ON TO BOSTON
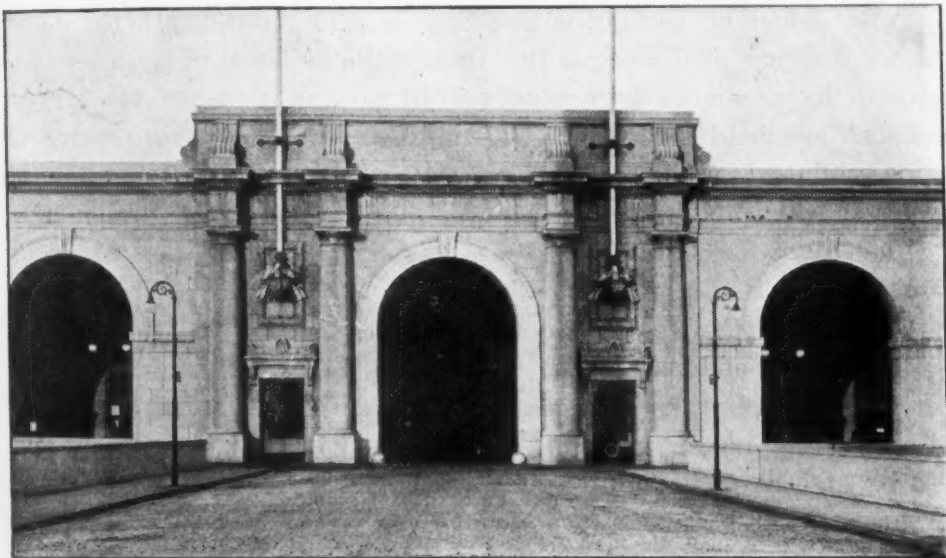
A LARGE percentage of members of the American Society for Steel Treating will make preparation to attend the Sixth Annual Convention and International Steel Exposition in Boston the week of September 22. Last year 56.2 per cent of the members

Commonwealth Pier, Boston, where the Sixth Annual Convention and Exposition
will be held September 22 to 26, 1924

of the Society were enrolled as present. This year gives every indication that there will be a higher percentage of members than at any of our previous conventions.

One has but to give a careful persual to the program as printed in the following pages of this issue, to realize why attendance at Boston is a prime requisite for successful attainment in the metal-

lurgical profession. The technical sessions each year have increased in valuable information and papers presented, and this year at Boston will be no exception.

It is rather difficult to conceive how any individual who values his own advancement and who can by any possible means arrange to attend, can neglect to do so. The Society is growing from year to year and increasing in usefulness and value to its membership. There is no doubt but that one of the greatest services it performs not only for its own members but for the iron and steel industry in general, is this annual convention.

Not only are the papers to be presented worthy of securing your attendance, but the opportunity to come into close contact with the leaders of the profession is one that should not be overlooked or passed by.

THE ANNUAL EXPOSITION

FROM a small beginning five years ago in the Seventh Regiment Armory of Chicago, the International Steel Exposition has grown by enormous percentages until now it is one of the largest expositions held annually. The number and interesting value of the exhibits have increased from year to year until at Boston the 1924 show will be 30 per cent larger than its immediate predecessor, which up to that time was the high mark of exposition activities of the A. S. S. T.

Practically twice the amount of space is required this year in order to accommodate those who desire to exhibit their products. It is rather remarkable and interesting to note that once a manufacturer has participated in an A. S. S. T. Exposition, he finds it to be such a worth while undertaking that he comes in year after year, quite as a matter of course. This is the highest compliment that could be paid to the intelligence of the members of the Society, and those who accept the opportunity to inspect the educational exhibit of metal working and metal treating equipment.

The show will be open during the five days of the Convention from 1.00 P. M. to 10.00 P. M., except on Thursday and Friday when the show will open at 10.00 A. M.

Following the usual custom, technical sessions will be held in the afternoon at the Exposition building where a number of symposia and round tables of particular interest to the industry will take place.

UNAUDITED PROFIT & LOSS STATEMENT
AMERICAN SOCIETY FOR STEEL TREATING.

From January 1 to June 30, 1924

INCOME

Dues (Gross)	$19,990.25	
Transactions Advertising	11,681.70	
Transactions Sales	983.00	
Bindery Account	442.50	
Discounts Received	72.48	
Interest	575.50	
Data Sheets	1,198.65	
Miscellaneous Receipts	494.72	
		$35,438.80

EXPENSES

Discounts Allowed	$ 97.84	
Bindery Account	281.80	
Reprints	93.68	
Data Sheets	2,472.07	
Library	51.06	
Miscellaneous Expenses	98.23	
Transactions	10,482.70	
Secretary's Office	5,007.14	
President's Office	73.00	
Treasurer's Office	999.15	
Director's Expenses	1,237.23	
National Committees	2,305.93	
Sectional Meetings	620.88	
Increase of Membership	22.53	
Local Chapters	8,237.32	$32,080.56
Excess of Income over Expense		3,358.24

BALANCE SHEET

ASSETS

Commercial Account Cleveland Trust Co. (St. Clair-E. 55th Br.)	$ 11.89	
Commercial Account Cleveland Trust Co. (East End Branch)	11,537.20	
Savings Account Cleveland Trust Co. (St. Clair-E 55th Br.)	2,714.67	
Savings Account Equity Savings & Loan Co	5,868.53	
Savings Account Union Trust Co	1,082.42	
Bond Investments	31,000.00	
U. S. Treasury Certificates	2,015.00	
Accounts Receivable for Advertising	1,799.28	
Accounts Receivable Miscellaneous	1,504.19	
Office Furniture & Fixtures	1,000.00	
1923 Convention Accounts Receivable	481.22	
1924 Convention Prepaid Expenses	5,218.50	
Inventory Jan. 1, 1924	2,119.48	
1925 Convention Prepaid Expenses	10.25	$66,362.63

LIABILITIES

Accounts Payable	$ 1,141.11	
Reserve for Dues Paid in Advance	10,000.00	
Reserve for Doubtful Accounts	1,000.00	
Permanent Convention Reserve	20,000.00	
Advance Receipts 1924 Convention	15,191.25	
H. M. Howe Medal Fund	3,000.00	
Surplus, January 1st, 1924	$12,672.03	
Profit from Jan 1st to June 30th, 1924	3,358.24	16,030.27	$66,362.63

DIRECTIONS FOR MEMBERS AND GUESTS

M EMBERS and friends arriving on the New York Central or
New York, New Haven and Hartford Railroads and stopping at Copley Square Hotels (Copley Plaza, Westminster, Lenox,
Brunswick, Vendome, Arlington and Somerset), are advised to get
off trains at Back Bay Station; or if arriving on the Boston and
Albany Railroad, it is advisable to leave train at the Huntington
Avenue Station.

If accommodations are taken at other hotels, leave train at
South Station, from either Boston and Albany, New York Central,
New York, New Haven and Hartford Railroads, or leave train at
North Station if arriving on the Boston and Maine Railroad.

The Essex Hotel is across the street from the South Station.

To Reach	From Back Bay Station	From South Station	From North Station
Commonwealth Pier	Go to South Station	Take Summer Street Extension surface car or buss at main exit	Take Atlantic Avenue Elevated to South Station; transfer to Summer Street Extension surface car
Copley Plaza and Copley Square Hotels	Walk to the right on Dartmouth Street.	Get off at Back Bay Station	Take Elevated surface car (Kenmore) —get off at Copley Station

To reach Commonwealth Pier from Copley Square, take any
northbound subway or surface car to Park Street, change to subway under for South Station, transfer to Summer Street Extension
surface car.

For the convenience of visitors arriving by automobile, the
Boston Chamber of Commerce maintains, during the tourist season,
a free information booth, where service is given as to road directions or conditions. This booth is located on the public mall at
Commonwealth Avenue, just west of Massachusetts Avenue. The
bulk of automobile visitors entering Boston from any direction
must pass near this booth. Descriptive booklets, road directions

or general New England information may be obtained in advance of arrival from the Chamber of Commerce.

Taxicabs are available at all stations.

The city regulations which govern the taxi fares are:

60 cents for the first mile.

40 cents for each succeeding mile.

20 cents for each additional passenger for the entire distance.

The minimum fare is approximately 40 cents.

List of **Hotels Showing Their Location in Respect to Copley Square and Commonwealth Pier**

Hotel	Number Rooms	Distance from Headquarters. Miles	Distance from Exposition. Miles	Address
Copley Plaza	500	0.0	2.25	Copley Square
Westminster	250	0.0	2.25	Copley Square
Brunswick	275	0.25	2.25	Boylston & Clarendon Sts.
Lenox	200	0.25	2.25	Exeter St.
Vendome	250	0.25	2.25	Commonwealth Ave.
Arlington	300	0.50	1.5	Arlington Sq. & Chandler St.
Touraine	225	0.75	1.75	Tremont & Boylston Sts.
Adams House	460	0.75	1.75	555 Washington St.
Somerset	300	0.75	3.00	Commonwealth Ave.
Avery	150	0.75	1.75	Washington & Avery Sts.
Parker House	321	1.00	1.25	Tremont & School Sts.
Bellevue	250	0.75	1.5	Beacon Hill
Young's	200	1.00	1.25	Court & City Hall Sts.
Essex	300	1.00	0.75	Atlantic Ave. & Essex St.
United States	250	1.00	1.00	Essex St.
Commonwealth	210	1.00	1.00	Bowdoin St., Beacon Hill
Boston Tavern	125	1.00	1.25	347 Washington St.
Healy's	75	0.75	1.75	642 Washington St.
American House	275	1.25	1.5	56 Hanover St.
Quincy House	500	1.25	1.5	Brattle St.

OUTLINE OF EVENTS

SIXTH ANNUAL CONVENTION A. S. S. T.

All morning technical sessions will be held in the Ball Room of the Copley Plaza Hotel. The afternoon sessions will be held in the Meeting Room at Commonwealth Pier.

Monday, September 22

Exposition open from 1:00 P. M. to 10:00 P. M.

10:00 A. M.—Technical Session, Ball Room, Copley Plaza.

1:00 P. M.—Exposition Opens.   Registration Begins.
2:30 P. M.—Technical Session, Meeting Room, Commonwealth Pier.
7:00 P. M.—Moving Pictures, Commonwealth Pier.

Tuesday, September 23

Exposition open from 1:00 P. M. to 10:00 P. M.

9:30 A. M.—Technical Session, Ball Room, Copley Plaza.
1:00 P. M.—Exposition Opens.
1:30 P. M.—Plant Visitation, Thomas G. Plant Co. or Waltham Watch Co.
2:30 P. M.—Technical Session, Meeting Room, Commonwealth Pier.
7:00 P. M.—Moving Pictures, Commonwealth Pier.
9:30 P. M.—Smoker and Entertainment, Ball Room, Copley Plaza.

Wednesday, September 24

Exposition open from 1:00 P. M. to 10:00 P. M.

9:30 A. M.—Annual Meeting of A. S. S. T., Ball Room, Copley Plaza.
10:30 A. M.—Technical Session, Ball Room, Copley Plaza.
1:00 P. M.—Exposition Opens.
1:30 P. M.—Plant Visitation, General Electric Co. or Naumkeag Co.
2:30 P. M.—Technical Session, Meeting Room, Commonwealth Pier.
7:00 P. M.—Moving Pictures, Commonwealth Pier.

Thursday, September 25

Exposition open from 10:00 A. M. to 5:30 P. M.

9:30 A. M.—Technical Session, Ball Room, Copley Plaza.
10:00 A. M.—Exposition Opens.
2:30 P. M.—Hardness Testing Symposium, Commonwealth Pier.
5:30 P. M.—Exposition Closes.
6:30 P. M.—Annual Banquet and Dance of the A. S. S. T., Ball Room,
          Copley Plaza.   Tickets at Registration Desk.

FRIDAY, SEPTEMBER 26

Exposition open from 10:00 A. M. to 10:00 P. M.

8:30 A. M.—A. S. S. T. Golf Tournament Begins.
9:30 A. M.—Technical Session, Ball Room, Copley Plaza.
10:00 A. M.—Exposition Opens.
1:30 P. M.—Inspection Harvard University, Massachusetts Institute of
          Technology and Charleston Navy Yard.
2:30 P. M.—Symposium on Metallurgical Education, Commonwealth Pier.
7:00 P. M.—Moving Pictures, Commonwealth Pier.
10:00 P. M.—Exposition Closes.

TECHNICAL PAPERS PROGRAM, SIXTH ANNUAL CONVENTION AMERICAN SOCIETY FOR STEEL TREATING, BOSTON, SEPTEMBER 22-26, 1924

Note: Registration begins at 1:00 p. m. at Registration Desk, Commonwealth Pier.

MONDAY, SEPTEMBER 22

Morning Session

Meeting in Ball Room, Copley Plaza Hotel.

10:00 A. M.—Address of Welcome—Mayor James M. Curley
Welcome by Boston Chapter—V. O. Homerberg
Address of Welcome—A. O. Fulton, General Chairman
Response—President George K. Burgess

Technical Session

Chairman—Dr. George K. Burgess

The Nature of the Function of Chromium in High Speed Steel —E. C. Bain and M. A. Grossmann, Atlas Steel Corporation.
The Use of Cobalt and Vanadium as Additions to High Speed Steel—Dr. W. Oertel and Dr. ing. F. Poelzgueter, Germany. (By title.)
The Law of Depression of Freezing Point as Applied to Metallic Alloys—Kotaro Honda and Toyato Ishigaki, Imperial University, Japan. (By title.)
Magnetic Determination of the Elastic State—A. V. deForest, American Chain Company.

Afternoon Session

1:00 P. M.—Exposition opens.
2:30 P. M.—Technical Session—Meeting Room, Commonwealth Pier.

Symposium on Salt Baths as Heating Media.
Chairman—A. H. d'Arcambal

Heat Treatment in Salt Baths—Major A. E. Bellis, Bellis Heat Treating Company.
Salt Baths—Sam Tour, Doehler Die Castings Company.
Fused Salt Baths for the Prevention of Soft Spots in Quenched High Carbon and Carburized Steels—W. J. Merten, Westinghouse Electric and Manufacturing Company.

Evening Session

Exposition open until 10:00 p. m.
7:00 P. M.—Moving Pictures.
8:00 P. M.—Meeting of Gage Steel Committee—Copley Plaza.

TUESDAY, SEPTEMBER 23

Morning Session

Meeting in Ball Room, Copley Plaza Hotel.

9:30 A. M.—Technical Session.
Chairman—Dr. John A. Mathews

Density and X-Ray Spectum of Hardened Ball Steel Drawn at Various Temperatures—K. Heindlhofer and F. L. Wright, SKF Industries, Inc.
The Application of X-Ray Crystal Analysis to Metallurgy— Dr. W. P. Davey, General Electric Company.
Spheroidized Cementite in Hypoeutectoid Steel—R. S. MacPherran and J. Fletcher Harper, Allis-Chalmers Mfg. Co.

A New Method of Interpreting Notched-Bar Impact Test Results—Dr. ing. Max Moser, Essen, Germany. (By title.)

A Laboratory Method for the Preparation of Small Steel Bars Differing Only in Carbon Content and the Effect of Changes in Carbide Concentration on the Specific Resistance—E. D. Campbell, University of Michigan and G. W. Whitney, American Smelting and Refining Company. (By title.)

The Microstructure of Austenite and Martensite—F. F. Lucas, Western Electric Company.

Afternoon Session

1:00 P. M.—Exposition opens.

1:30 P. M.—Plant Visitation, Thomas G. Plant (Manufacturer of Queen Quality Shoes), or Waltham Watch Company.

2:30 P. M.—Technical Session—Meeting Room, Commonwealth Pier.
Chairman—Professor H. M. Boylston

The Intrinsic Value of Heat Sources versus the Floating Economic Value of the B. t. u.—E. F. Collins, General Electric Company.

Selection of Fuel for the Heat Treatment of Metal—J. A. Doyle, W. S. Rockwell Company.

Gas as a Factor in Improving Quality Standards and Lowering Production Costs of Heat Treated Steel—H. O. Loebell, Combustion Utilities Company.

Evening Session

Exposition open until 10:00 p. m.

7:00 P. M.—Moving Pictures.

9:30 P. M.—Annual Smoker and Entertainment, Ball Room, Copley Plaza Hotel.

WEDNESDAY, SEPTEMBER 24

Morning Session

Meeting in Ball Room, Copley Plaza Hotel.

9:30 A. M.—Annual Meeting of the American Society for Steel Treating.
Chairman—Dr. George K. Burgess

Report of Chapter Delegates.

Technical Session

Observations Upon the Making and Use of Tool and Special Alloy Steels—Dr. John A. Mathews, Crucible Steel Company of America.

Some Fundamental Factors for Obtaining Sharp Thermal Curves—Carl Benedicks, K. G. Lund and W. H. Dearden, Stockholm, Sweden. (By title.)

Granulation Hypothesis and the Delta-Gamma Change in Iron-Carbon and Nickel Alloys—Colonel N. T. Belaiew. (By title.)

Correlation of Endurance Properties of Metals—D. J. McAdam, Jr., Naval Experimental Station, Annapolis.

On the Transformations in Pure Iron—Kotaro Honda, Imperial University, Japan.

Afternoon Session

1:00 P. M.—Exposition opens.

1:30 P. M.—Plant Visitation, General Electric Company, Lynn, or Naumkeag Manufacturing Co., Salem (Textile Mill).

2:30 P. M.—Technical Session—Meeting Room, Commonwealth Pier.
Chairman—Colonel A. E. White

The Heat Treatment of Automobile Parts—J. M. Watson, Hupp Motor Car Company (Illustrated with a motion picture.)

Die Records and Their Effects on Die Costs—E. J. P. Fisher, R. Wallace and Sons Mfg. Company.

Heat Treatment of Tool Steel—F. C. A. H. Lantsberry, Jessop Steel Co., Sheffield, England.

Progress in the Manufacture and Use of Clay Refractories—W. G. Owen, Haws Refractories Company.

Evening Session

Exposition open until 10:00 P. M.

7:00 P. M.—Moving Pictures.

THURSDAY, SEPTEMBER 25

Morning Session

Exposition opens at 10:00 A. M.
Meeting in Ball Room, Copley Plaza Hotel.

9:30 A. M.—Technical Session.
Chairman—Dr. Albert Sauveur

Quenching Diagrams for Carbon Steels in Relation to Some Quenching Media for Heat Treatment—H. J. French and O. Z. Klopsch, Bureau of Standards.

A New Theory of Overstrain and Strength of Materials—H. P. Troendly and G. V. Pickwell, Wm. D. Gibson Company.

X-Ray Tests Applied to the Problems of the Steel Foundry—Dr. H. H. Lester, Watertown Arsenal.

Influence of the Structure "as cast" upon the Manufacture and Qualities of Some Alloyed, Especially High Speed Steels—Dr. ing. Franz Rapatz, Duesseldorf, Germany. (By title.)

The Effect of Various Reductions in Forging upon the Physical Properties of Steel—D. J. McAdam, Jr., U. S. Naval Experimental Station, Annapolis.

Afternoon Session

2:30 P. M.—Technical Session, Meeting Room, Commonwealth Pier.

Hardness Testing Symposium, National Research Council.
Chairman—Dr. H. P. Hollnagel

Comparison of Brinell and Rockwell Hardness of Hardened High Speed Steel—S. C. Spalding, Halcomb Steel Company.

The Relation of Hardness and Impact Measurements to Performance—G. W. Webster, Bellis Heat Treating Company.

Relation Between Rockwell and Brinell Hardness Scales—Irving H. Cowdrey, Massachusetts Institute of Technology.

The Ball Indentation Hardness Test—Dr. S. L. Hoyt, General Electric Company.

Report on Hardness Testing Work of A. S. M. E. Committee on Cutting Metals—Major A. E. Bellis, Bellis Heat Treating Company.

5:30 P. M.—Exposition closes.

Evening Session

6:30 P. M.—*Annual Banquet and Dinner Dance of the American Society for Steel Treating*, Ball Room, Copley Plaza Hotel. Tickets at Registration Desk.

FRIDAY, SEPTEMBER 26

Morning Session

Exposition opens at 10:00 A. M.

9:30 A. M.—Technical Session—Ball Room, Copley Plaza Hotel.
Chairman—Dr. Zay Jeffries

Stainless Iron and Steel—T. Holland Nelson, United Alloy Steel Corporation.

Stainless Steel and Stainless Iron—O. K. Parmiter, Firth-Sterling Steel Company.

Tensile Properties of Some Steel Wire at Liquid Air Temperatures—W. P. Sykes, National Lamp Works of General Electric Company.

Grain Boundaries in Steel—Cecil H. Desch, England. (By title.)

Macroscopic Examination of Steel—V. O. Homerberg, Massachusetts Institute of Technology.

The Secondary Crystallization in Iron-Carbon Alloys—Dr. Vsevolod N. Krivobok, Carnegie Institute of Technology.

Afternoon Session

1:00 P.M.—Tour through Harvard University, Massachusetts Institute of Technology and Charleston Navy Yard.

2:30 P. M.—Technical Session—Meeting Room, Commonwealth Pier.
Symposium on Metallurgical Education.
Chairman—Dr. O. E. Harder

Metallurgical Education—Bradley Stoughton, Lehigh University.

On Metallurgical Education—Dr. S. L. Hoyt, General Electric Company.

Paper—Professor D. J. Demorest, Ohio State University.

Evening Session

7:00 P. M.—Band Concert.
10:00 P. M.—Exposition Officially Closes.

LIST OF EXHIBITORS AND WHAT THEY WILL EXHIBIT AT THE INTERNATIONAL STEEL EXPOSITION, BOSTON, SEPTEMBER 22-26, 1924

Abrasive Machine Tool Co., East Providence, R. I. Section C, Booth 205.

Exhibiting (in operation): A No. 3 Abrasive surface grinder, equipped with exhaust system, magnetic chuck and self-contained generator for operating same. Motor driven. A No. 33 Abrasive vertical spindle surface grinder, equipped for wet grinding, magnetic chuck and self-contained generator for operating same. Motor driven. Various units of each machine to illustrate construction.

In Attendance: Norman D. MacLeod, C. Gordon MacLeod, Kenneth B. B. MacLeod and Harry H. Flint.

Acme Machine Tool Co., Cincinnati. Section C, Booth 221.

Exhibiting (in operation): A Cincinnati Acme No. 2 Universal flat turret lathe, featuring the production possibilities of this type of machine. Machine will be tooled up and will produce parts.

In Attendance: Charles Meier, works manager; A. T. Stehn, service engineer, and Carl Linden, factory sales engineer.

Adams and Durkee Steel Co., Inc., Boston. Section A, Booth 55.

Exhibiting: Samples of bar steel, tubing, spring wire and small tools.

In Attendance: Messrs. Adams, Durkee, Osgood, Howard and Ruef.

Air Reduction Sales Co., New York City. Section B, Booths 134 and 144.

Exhibiting (in operation): Airco-Davis-Bournonville specially designed machines for oxyacetylene cutting. Airco oxygen. Airco acetylene. Airco-Davis-Bournonville hand welding and cutting apparatus and other Airco products.

In Attendance: L. Edwards, J. A. Shand, P. Wilder, G. Jaeger and G. Van Alstyne.

Allen Co., Chas. G., Barre, Mass. Section C, Booth 239.

Exhibiting (in operation): A four-spindle Allen ball bearing drilling machine with power-feed and lubricating equipment. A two-spindle Allen ball bearing drilling machine with silent chain motor drive. A single one-spindle plain-bearing drilling machine.

In Attendance: Harding Allen.

American Gas Association, New York City. Section A, Booths 19 and 20.

. Exhibiting: Literature with reference to the use of gas for industrial purposes.

In Attendance: N. T. Sellman, assistant secretary-manager.

American Gas Furnace Co., Elizabeth, N. J. Section A, Booths 9 and 10.

Exhibiting (in operation): Continuous heating machine; automatic quenching tank; carburizing machine. Automatic temperature controllers. High speed steel hardening furnace and lead and cyanide hardening furnace. Brass melter; burners and blowpipes. High heat test furnace. Small high pressure gas booster. Display of furnaces and heating machines.

In Attendance: Gustav Schwab, Theodore Farwick, Sr., John Mehrman, Theodore Farwick, Jr., Edward D. Knapp, S. P. Rockwell, W. D. Fuller and P. C. Osterman.

American Machinist, New York City. Section C, Booth 247.

Exhibiting: Sample copies of "American Machinist."

In Attendance: Mason Britton, F. S. Weatherby, J. A. McGraw, Ellsworth Sheldon and Robert Nelson.

American Metallurgical Corporation, Boston. Section B, Booth 98.

Exhibiting (in operation): An electric heat treating furnace (open resistor box type). An electric lead and cyanide pot type furnace.

In Attendance: K. A. Juthe, president and general manager; Albert J. Hanson, chief engineer; Stanley N. Juthe, sales manager; Arthur C. Wright, sales engineer, and William Walker, works superintendent.

American Stainless Steel Co., Pittsburgh. Section A, Booth 52.

Exhibiting: A varied assortment of articles made from stainless steel.

In Attendance: John C. Neale, president, and C. S. Bunting, secretary-treasurer.

American Tool Works Co., Cincinnati. Section C, Booth 237 and 238.

Exhibiting (in operation): A 20-inch American heavy service back-geared crank shaper arranged for motor drive through a 4-change speed box. A 12"x5' American high duty lathe with patented 12-speed geared head arranged for self-contained motor drive with motor mounted in leg, taper attachment, Universal relieving attachment, oil pan, and cooling equipment. A 3-foot American high-speed sensitive radial drill with tapping attachment and plain box table arranged for motor drive with motor mounted on rear of arm. A 2½-foot American high-speed ball bearing radial drill with round table arranged for motor drive through a 6-change speed box. A 20"x10' American High duty lathe with patented 12-speed geared head arranged for motor drive, high duty screw tool post. A 4-foot American triple plain radial drill with plain box table arranged for motor drive through an 8-change speed box.

In Attendance: H. W. Schatz and F. L. Stubenroth, demonstrator.

American Twist Drill and Tool Co., Detroit. Section B, Booth 161.

Exhibiting (in operation): High speed twist drills.

In Attendance: C. G. Munn and S. Sowder.

Andresen and Associates, Inc., F. C., Pittsburgh. Section B, Booth 159.

Exhibiting: "Fuels and Furnaces," containing a complete treatise on the "Heat Treatment of Steel," written by Francis B. Foley, Bureau of Mines, Rolla, Mo.

In Attendance: E. C. Cook.

Armstrong-Blum Manufacturing Co., Chicago. Section B, Booth 139.

Exhibiting (in operation): Marvel metal-cutting machines; automatic high-speed saw; metal band saw; portable hack saw machines; punching, shearing and bending machines.

In Attendance: Harry J, Blum, secretary.

Armstrong Cork and Insulation Co., Pittsburgh. Section B. Booth 131.

Exhibiting: Nonpareil insulating brick for furnaces, ovens and boiler settings. Nonpareil high pressure covering and blocks for steam lines, heaters, boilers, breechings, ovens and other high-temperature equipment. Nonpareil cork covering for refrigerating drinking water lines,

brine and ammonia lines. Nonpareil corkboard for roof insulation, cold storage and constant temperature rooms, tanks, etc. Linotile and Armstrong's cork tile floors.

In Attendance: F. W. Robinson, H. B. Gates, W. D. Thompson and C. A. Senter.

Atkins and Co., Inc., E. C., Indianapolis. Section B, Booth 112.

Exhibiting (in operation): A No. 3 Atkins metal-cutting bandsaw machine. Atkins KWIK-KUT machines. Atkins circular metal-cutting saws. Atkins AAA hacksaw blades. Atkins silver steel wood-cutting saws and Atkins Cantol belt wax.

In Attendance: Edward S. Norvell, manager, metal-cutting department; J. I. Kipp, salesman; R. P. Smith, salesman, and W. R. Chapin, metallurgist.

Atlas Steel Corporation, Dunkirk, N. Y. Section B, Booth 168.

Exhibiting: Hot rolled and cold drawn tool steel and special alloy steel products. Forged high-speed products. Sample tools, and dies with records of performance.

In Attendance: H. J. West, W. H. Wills, F. B. Lounesberry, C. P. Burgess and S. S. Stratton.

Avey Drilling Machine Co., Cincinnati. Section C, Booth 221.

Exhibiting (in operation): A two-spindle No. ½ Avey drilling machine with tapping attachment. A one-spindle No. 1 Avey drilling machine, full automatic feed. A two-spindle No. 2 Avey drilling machine full automatic feed and with tapping unit. A two-spindle No. 3 Avey drilling machine with power feed. A No. 2 Avey tool room drilling machine. All motor driven.

In Attendance: J. G. Hey, J. F. Mirrielees and L. H. Pratt.

Baker Brothers, Inc., Toledo, Ohio. Section C, Booth 221.

Exhibiting (in operation): A No. 121 quick change type, light heavy duty drilling and boring machine, capacity ⅜ to 1½ inches, arranged for motor drive with compound table. A No. 24 cam feed automatic drilling machine, which is a production machine with a maximum capacity of 1½ inch high-speed drills in steel.

In Attendance: W. W. Elliott, H. L. Tigges and Wm. Baker.

Banner Rock Products Co., Alexandria, Ind. Section B, Booth 146.

Exhibiting: Rock Wool and Rock Cork in jacket, blanket and block form. These products run from 86 to 96 per cent air void.

In Attendance: Corydon H. Hall, treasurer and R. A. Smith.

Barber-Colman Co., Rockford, Ill. Section C, Booths 201 and 202.

Exhibiting: Barber-Colman gear hobbing machines; Barber-Colman hob sharpening machines; Barber-Colman milling cutters and hobs; John Universal vise chuck and reversing tapping chuck; Barber-Colman working tying machine and Barber-Colman hand knotters. The last two items are a part of this company's complete line of automatic textile machinery, which they desire to exhibit in connection with their machine tools, as examples of work produced in their shops. The large size hobbing machine will be in operation, producing commercial gears of different sizes. The warp-tying machine will also be demonstrated.

In Attendance: F. G. Hoffman, sales manager; C. M. Cheadle, Jr., and E. F. Linderoth.

Bath and Co., Inc., John, Worcester, Mass. Section A, Booth 37.

Exhibiting: Bath high-speed steel ground thread taps—standard and special. Bath high-speed steel thread rolling dies. Bath high-speed steel ground thread mills. Bath high-speed steel ground gear hobs. Bath high-speed steel ground plug thread gauges. All of the above are ground from the solid. Bath internal micrometer and Bath internal thread micrometer, which measure holes to tenths of thousandths.

In Attendance: John Bath, J. Chester Bath and Robert E. Lamb.

Bausch and Lomb Optical Co., Rochester, N. Y. Section A, Booth 45.

Exhibiting (in operation): Complete line of metallurgical microscopes and metallographic apparatus, including a new automatic feed arc lamp. A new series of optical systems by means of which the area of flatness of the image may be increased. Contour measuring projector, by means of which the contours of finished products may be checked and inspected.

In Attendance: I. L. Nixon, W. L. Patterson and E. H. Anthes.

Bay State Tap and Die Co., Mansfield, Mass. Section B, Booth 175.

Exhibiting (in operation): Complete line of taps, dies, drills, die stocks, tap wrenches and screw plates. Anderson dial tapper demonstrating the company's new spiral fluted production tap in actual operation; also a drill press, demonstrating Bay State drills.

In Attendance: Fred W. Day.

Bellis Heat Treating Co., New Haven, Conn. Section A, Booth 6.

Exhibiting (in operation): Bellis Lavite Furnaces. Also Carbon Lavite; tempering Lavite and high-speed Lavite.

In Attendance: A. E. Bellis, president; J. W. Black, superintendent; G. W. Webster, metallurgist; J. M. Dunlevy, sales manager; G. C. Davis, New England representative; C. B. Kennedye, Western representative, and R. C. Jordan, Philadelphia representative.

Bethlehem Steel Co., Bethlehem, Pa. Section A, Booths 36 and 47.

Exhibiting: Samples of raw materials, sections of ingots, etc. This exhibit emphasizes the fact that this company has the facilities for the exclusive production of those materials requiring the greatest care and skill in manufacture.

In Attendance: C. E. Chamberlin, R. E. Belknap, R. B. Wallace, John F. Lennon, A. P. Spooner, Henry Wysor, W. R. Shimer, G. C. Lilly, H. C. Bigge, Walter Trumbauer, R. H. Christ and G. A. Richardson.

Blakeslee Co., G. S., Chicago. Section C, Booth 249.

Exhibiting: Metal washing machines.

In Attendance: Chicago and Boston representatives.

Blanchard Machine Co., Cambridge, Mass. Section C, Booth 221.

Exhibiting (in operation): Blanchard automatic surface grinder, No. 16-A, in operation on production work. Blanchard high-power surface grinder, No. 16. Blanchard demagnetizer. Samples and photographs of work being done by users of all sizes of surface grinding machines.

In Attendance: F. E. Bartley and H. F. Skillings.

Bristol Co., Waterbury, Conn. Section B, Booths 99 and 100.

Exhibiting (in operation): Complete line of temperature measuring devices and temperature control operators.

In Attendance: H. L. Griggs and L. G. Bean.

Brown and Sharpe Mfg. Co., Providence, R. I. Section C, Booths 218 and 219.

Exhibiting (in operation): Automatic milling machine; grinding machine and automatic screw machine.

In Attendance: A. E. Mandeville and J. G. Swinburne.

Brown Instrument Co., Philadelphia. Section B, Booth 132.

Exhibiting: Indicating pyrometers with single and double scales, equipped with automatic cold junction compensating devices, and in aluminum cases especially designed for protection against dirt. Portable pyrometer. Precision potentiometer graduated 0-50 millivolts, incorporating the unusual 96" scale, capable of being read to 0.01 millivolts. Automatic control indicating pyrometer for automatically controlling gas or oil fired furnaces or electrically heated furnaces. Medium high resistance indicating pyrometer. Indicating control thermometer for closely controlling temperature of quenching baths, etc. Single record, continuous chart recording pyrometer. Duplex continuous recording pyrometer, which makes two records on one chart side by side for instant comparison. Round chart recording pyrometer for use where 24-hour record is required. Six-record multiple continuous recording pyrometer for recording temperatures of six thermocouples at one time on one chart. Eight-inch recording thermometer for taking the temperature of oil baths, etc. This instrument incorporates a means of re-calibrating, a method of adjusting the pressure of the pen on the paper and an automatic device which lifts the pen from the paper when the door is open. Transformation point recorder complete with furnaces for accurately determining transformation points of steel. Recording signalling pyrometer, which operates three lamps, showing red when the temperature of the furnace is too high, green when it is too low, and white when it is just right. Thermocouples and protecting tubes, including nickel chromium tubing; pure, drilled, nickel tubing, special porcelain and quartz, protecting tubes for high temperatures, calorized tubes, and special thermocouples for use with Bellis Lavite, etc. Motor-operated control valves for gas and oil fired furnaces, incorporating a means of adjusting the air and fuel valves so that the ratios will be kept constant when the control pyrometer is functioning. Electric panel for electrically heated furnaces. Bausch & Lomb Bal-Opticon for showing pictures of important installations, details of the instruments and interesting and instructive sample charts.

In Attendance: R. P. Brown, president; G. W. Keller, sales manager; J. D. Andrews, New York district manager; G. P. Beck, New England district representative; C. L. Simon, technical director of advertising; G. G. Goodman, G. J. Egbert, New York representatives; W. S. Koop, sales promotion department.

Brown Lynch Scott Co., Monmouth, Ill. Section B, Booth 128.

Exhibiting (in operation): Carburizing compound cleaner and grader.

In Attendance: J. A. Scott and J. D. Tracey.

Bureau of Standards, Washington, D. C. Section B, Booth 176.

Exhibiting: Equipment available at the Bureau of Standards for research and testing and which will illustrate the fields of cooperation

with various industries. Special attention will be paid to metallurgical work and in particular that relating to irons and steels, but the work of the paper, textile, rubber, leather, cement, optical glass and other sections will also be illustrated. There will be on hand a case containing standard chemical samples, including some of the newer ones recently prepared, and a set of the Bureau's precision gage blocks. Researches considered of special interest to members of the Society and their guests, will also be illustrated by small models or photographs and transparencies. These will include properties of metals at various temperatures, the study of quenching media for heat treatment, etc. Sets of publications will be at hand for examination by those interested, and there will be installed and in continuous operation, a projection lantern, which will permit a more complete demonstration of the field of activities of the Bureau.

In Attendance: Dr. G. K. Burgess, director; H. W. Gillett, H. J. French, T. G. Digges and O. Z. Klopsch.

Calorizing Co., Pittsburgh. Section A, Booths 21 and 28.

Exhibiting (in operation): Heat-enduring material consisting of Calorized steel annealing box, Calorized pressed steel lead pot, Calite alloy carbonizing box, section of Calite furnace skid rail and Calite I-beam. Sectional view of the company's Calorized metallic recuperator. Small furnace and recuperator under heat.

In Attendance: J. A. Wilson, sales engineer; A. V. Farr, vice-president; Wm. M. Smith, sales engineer and George M. Davis, district manager.

Campbell Co., Inc., A. C., Bridgeport, Conn. Section C, Booth 243.

Exhibiting (in operation): A No. 1 Campbell nibbling machine, cutting $\frac{7}{8}$-inch steel plates. A No. 1-B Campbell nibbling machine, cutting $\frac{7}{8}$-inch steel plates (large). A No. 2 Campbell nibbling machine, cutting $\frac{3}{8}$-inch steel plates.

In Attendance: Stuart Naramore and others.

Carborundum Company, Perth Amboy, N. J. Section A, Booth 18.

Exhibiting (in operation): Heat treating furnace of new design. Standard Carbofrax, Refrax, Aloxite and Magnesite high temperature fire brick; high temperature fireclay cement; high temperature carborundum cements. Carbofrax pyrometer protection tubes. Carbofrax hearths, muffles, supports, etc., for heat treating furnaces. Display board of small Carborundum and Aloxite abrasive wheels.

In Attendance: J. C. Rice, J. A. King, C. E. Hawke and S. A. Fenno.

Carpenter Steel Co., Reading, Pa. Section B, Booth 150.

Will distribute souvenirs of products manufactured.

In Attendance: G. H. Edmonds, Reading office, F. A. Bigelow, president, J. H. Parker, vice-president, C. A. Heil, district sales manager, C. W. Olsen, district sales manager, J. M. Millard, sales representative, J. A. Phillips, Jr., sales representative, B. H. DeLong, metallurgical engineer, G. B. Luerssen, metallurgical department, and W. H. Kemper, metallurgical department.

Case Hardening Service Co., Cleveland. Section A, Booth 29.

Exhibiting: BOHNITE—the original compound made by the process of impregnating the energizer inside the compound. BOHNITE by reason of these processes is the same energetic compound the sixth heat as it is at the first heat and sometimes as far even as the eighth heat. CASEITE—a cyanide process—all of the effectiveness of cyanide at

least cost. NON-CASE—a paint applied to surfaces not to be .car-burized, which prevents carburization of those surfaces. HI-TEMPO —heat resisting metal. Recently put on the market after several years of experience, now used for pots and boxes, hearth plates, gal-vanizing boxes, annealing boxes and a dozen special uses—new ones being developed every day. For use wherever there is heat. It is quite inexpensive. CLEANCOAT, BATHITE, DRAWITE and a com-plete line of case hardening materials.

In Attendance: W. C. Bell, E. J. Gossett and J. S. Ayling.

Celite Products Co., Chicago. Section A, Booth 11.

Exhibiting (in operation): Sil-O-Cel insulating brick and powder for furnaces, boilers, etc.; Sil-O-Cel C-3 concrete for lining furnace doors and for insulating furnace spaces. FRAXITE high temperature cem-ent for laying and facing fire brick. There will be a gas torch playing on Sil-O-Cel brick, showing non-conducting properties, as well as small electric furnace with one-half of top fire brick, other half Sil-O-Cel brick, showing difference in heat transmission.

In Attendance: E. A. Phœnix of Chicago and E. J. Weaver of Boston.

Central Steel Co., Massillon, Ohio. Section B, Booths 126 and 138.

Exhibiting: Photographs of plant operations. Parts made of alloy steels. Assembled transmission (in operation). Hot tops from ingots; display of gears and die blocks.

In Attendance: P. J. Griffiths, president and general manager; J. M. Schlendorf, vice-president in charge of sales, and B. F. Fairless, vice-president in charge of operations. From sales department: W. M. Garrigues, assistant general manger of sales; D. B. Carson, assistant sales manager, T. B. Davies, Syracuse district sales manager; A. Schaeffer, Detroit district sales manager; Frank Wallace, Philadel-phia district sales manager; G. W. Wagstaff, Chicago district sales manager; F. L. Gibbons, Cleveland district sales manager, and C. C. Willits, New York district sales manager. From metallurgical de-partment: E. C. Smith, chief metallurgical engineer; C. P. Richter, assistant chief metallurgical engineer; W. W. Leffler, M. J. R. Morris and R. K. Bowden, metallurgical engineers. From operating depart-ment: W. M. Lindsay, chief mill metallurgical engineer, and H. M. Cox, chief inspector sheet division.

Cincinnati Bickford Tool Co., Cincinnati. Section C, Booth 221.

Exhibiting (in operation): A 21-inch direct drive, movable head, upright drill, equipped with round table, power-feed, tapping attachment, chip pan cutting lubricant outfit, geared-motor drive. A 21-inch sliding head, upright drill, equipped with round tilting table, power-feed, tapping attachment, chip pan cutting lubricant outfit, geared-motor drive. A 3-foot 24-speed plain radial drill, equipped with plain table, cutting lubricant outfit, motor and speed box drive.

In Attendance: S. K. Wallace, L. D. Quackenbush, Wm. F. McCarthy, H. A. Prentiss, D. F. Shaw, J. F. McCarthy and E. D. Crockett.

Cincinnati Grinder Co., Cincinnati. Section C, Booth 237.

Exhibiting: Grinding machines.

In Attendance: J. H. Peckham.

Cincinnati Milling Machine Co., Cincninnati. Section C, Booth 221.

Exhibiting (in operation): A No. 4 plain high power milling machine of the new type arranged for chain motor drive. Machine will be operating on demonstration work. A No. 2-M Universal, rigged up

for a typical tool room job. This machine will also be arranged for chain motor drive. A new 8-inch plain grinder, which will operate on a production job, as will the centerless grinder, the fourth machine in this company's booth.

In Attendance: R. L. Morrissey, J. H. Peckham, A. C. Hoefinghoff and W. W. Tangeman.

Cincinnati Planer Co., Cincinnati. Section C, Booth 221.

Exhibiting (in operation): A 36"x36"x8' HYPRO planer.

In Attendance: Carl Linden and George Langen.

Cleveland Twist Drill Co., Cleveland. Section C, Booth 246.

Exhibiting (in operation): Two drill presses demonstrating CLE-FORGE high-speed drills.

In Attendance: H. O. Swan, Fred Hoelzle, Tom Skove, W. C. Weidig, F. A. Kelly and H. P. Jenson.

Cochran-Bly Co., Rochester, N. Y. Section C, Booth 240.

Exhibiting (in operation): Metal sawing machine and automatic saw sharpening machine.

In Attendance: W. H. Welch and S. M. Crandall.

Colonial Steel Co., Pittsburgh. Section A, Booth 43.

Exhibiting: High-speed and carbon tool steel for machine shop and metal-cutting tools. Hollow and solid bars for mining and rock drilling purposes. Carbon tool steel bars for blacksmith and foundry use; hammers, chisels, wedges, etc. Tool steel bars for machine parts. Tool steel sheets and circles for saws and knives. Bars and billets for manufacture of oil well drilling tools. Forging billets. Steel plates to be manufactured into plows, cultivators and harvesting machinery. Blocks and forgings for drop forging dies and trimmer knives.

In Attendance: J. Trautman, Jr., N. B. Hoffman, E. P. Fitzgerald, James F. Mitchell, Arthur C. Muller, Alan F. Harden, P. S. Crooker and W. H. McDonald.

Combustion Utilities Corp., New York. Section A, Booth 15.

Exhibiting (in operation): Automatic heat treating furnace. Exhibit showing principle of recuperation. Exhibit of electricity versus gas. Small heat treating furnace, stock carburizing and lead hardening furnace. Exhibit of 1923-24 advertising matter and hundreds of pictures of installations.

In attendance: C. B. Phillips.

Consolidated Gas Company, Boston. Section A, Booths 2 and 3.

Exhibiting (in operation): Various appliances for the use of gas for industrial purposes.

In Attendance: J. C. D. Clark, industrial sales manager.

Cooper-Hewitt Co., Hoboken, N. J. Section C, Booth 203.

Exhibiting (in operation): Cooper-Hewitt WORK-LIGHT, a means of illumination for all types of machine tool plants. The lamp consists of an auxiliary and a 50-inch tube of luminous vapor, which emits a well diffused and practically monchromatic light, 90 per cent of which is in the green band of the spectrum. Section C of the Exhibition will be illuminated with 75 Cooper-Hewitt "WORK-LIGHT" units.

In Attendance: C. F. Strebig, general sales manager; R. D. Mailey, factory manager and chief engineer; J. E. Watkins, district sales manager; D. R. Grandy, commercial engineer; E. C. Donegan, advertising manager; A. S. Hubbard and A. H. Kuehne.

Crescent Washing Machine Co., New Rochelle, N. Y. Section C, Booth 212.

Exhibiting (in operation): Model No. 2A automatic Crescent Metal-Cleaning Machine, 9 feet long, 5 feet 5 inches high and 38 inches wide. This machine is equipped with an automatic conveyor, driven by a half horsepower motor. Operating width is 26 inches, operating height, 18 inches. Washing unit is equipped with two four-way revolving wash arms supplied with 225 gallons per minute by an E-4 pump, driven by a one and one-half horsepower motor. Tank capacity is 100 gallons. Also two 5,000-watt bayonet type electric heating units will be exhibited, although they will not be installed in the machine.

In Attendance: C. S. Tompkins, sales engineer in eastern territory, and E. C. Arndts, sales engineer in Ohio.

Crucible Steel Company of America, New York City. Section A, Booths 39, 40, 41, 50 and 51.

Exhibiting: Steel and steel products.

In Attendance: A. H. Kingsbury; E. C. Collins, president; Dr. John A. Mathews, vice-president; A. T. Galbraith, general manager of sales; R. Michener, general sales agent; R. E. Christie, assistant general sales agent; C. M. Johnson, J. O. Rinek, A. E. Van Cleve, A. B. Day, O. W. Geer, R. W. Crane, F. J. Dawless, G. E. Leffingwell, W .H. Plage and S. H. Beerman.

Davison Gas Burner and Welder Co., N. C., Pittsburgh. Section A, Booth 8.

Exhibiting (in operation): A special small oil burner using from ½ to 1 gallon of oil per hour with a special feed pump. This company will have a furnace equipped with their Vesuvius fuel oil burner, using low pressure air at 3 ounces. In this connection they will also show an oil pumping outfit-temperature control.

In Attendance: N. C. Davison, M. E. Kuhn and Edward Poor.

Dearborn Chemical Co., Chicago. Section A, Booth 61.

Exhibiting: NO-OX-ID—the Original Rust Preventive.

In Attendance: E. M. Converse, director, department of specialties, W. H. Fairlamb, Chicago, C. I. Loudenback, Detroit, P. H. Hogan, Boston, and Arthur Stuart, Boston.

Disston and Sons, Inc., Henry, Philadelphia. Section B, Booth 122.

Exhibiting (in operation): Milling saws; band saws. Display boards showing slitting saws, milling saws, hack-saw blades, files, etc.

In Attendance: Joseph L. Dorrington and Edward P. Ludy.

Donner Steel Co., Inc., Buffalo, N. Y. Section B, Booth 117.

Exhibiting: Steel and steel products. Booth will also be used for reception purposes.

In Attendance: W. F. Vosmer, vice-president.

Driver-Harris Co., Harrison, N. J. Section A, Booth 59.

Exhibiting: Castings; carburizing containers and furnace parts made and sold under the company's trade mark "Nichrome."

In Attendance: G. A. Lennox, New England manager; J. B. Shelby, Harrison office; W. B. Blythe, manager, Detroit office; H. D. McKinney, manager, Chicago office; Arlington Bensel, first vice-president and general sales manager; G. A. Rickert, advertising manager, and H. O. Hartdegan, Canadian representative.

Dycast Steel Co., Collinsvile, Conn. Section C, Booth 210.

Exhibiting: Tool steel castings and bars; high speed steel punches and dies—hot work; blanking dies and punches—cold cutting; special alloy cold striking dies cast to form; high speed steel cast cutting tools. Composite high speed tools cast to form on a soft steel back.

In Attendance: A. C. Davidson, manager, and others.

Eaton Electric Furnace Co., Taunton, Mass. Section B, Booth 125.

Exhibiting (in operation): A No. 1 model "J" Eaton Electric tool hardening furnace. Oven chamber, 10 inches wide, 15 inches deep, for continuous temperatures up to 1700 degrees Fahr. For use principally in tool rooms and machine shops and for odd jobs. A No. 3 model "RR" Eaton Electric rotary tempering furnace, for large production of small parts, such as lock washers, drills, bobbin rings, springs (flat and coil), etc. Size of loading container, 36 inches deep, 14 inches in diameter. For temperatures up to 800 degrees Fahr. A small working model of No. 1 model "J" furnace. This model is one-fifth the size of the actual furnace, which will also be on exhibit. This small model will not be operated, but is for demonstrating the method of replacing heating coils when required.

In Attendance: H. B. Eaton, sales manager; Murray Winter, treasurer, and A. A. Harvey, engineering department.

Engelhard, Inc., Charles, New York City. Section A, Booth 66.

Exhibiting (in operation): Automatic control for gas and electric furnaces. Indicating and recording pyrometers. Thermocouple mountings for plant and laboratory work. A new development in recording pyrometer instruments.

In Attendance: R. W. Newcomb, E. S. Newcomb, J. H. Allison, M. K. Epstein and C. W. Hubbard.

Federal Machine and Welder Co., Warren, Ohio. Section B, Booth 92.

Exhibiting (in operation): An electric butt-welding machine. Also samples of various size steel for demonstration.

In Attendance: F. P. McBerty, Z. A. McBerty, A. V. B. Cutler and Albert E. Hackett.

Firth-Sterling Steel Co., McKeesport, Pa. Section B, Booths 135 and 145.

Exhibiting (in operation): Blue Chip high-speed steel tools. Miscellaneous tools. Stainless steel and stainless iron articles. Globe drill-rods and bright stainless strips.

In Attendance: E. E. Roberts, Al Mattson, O. T. Smith, J. F. Higgins, H. I. Moore, F. Miller, A. E. Barker, E. T. Jackman, R. F. Kimber, A. C. Leete and D. G. Clark.

Fitchburg Machine Works, Fitchburg, Mass. Section C, Booth 250.

Exhibiting: Lo-Swing Lathes and Star Lathes.

In Attendance: E. R. Smith, vice-president.

Ford Co., **J. B., Wyandotte, Mich.** Section A, Booth 25.

Exhibiting: Wyandotte cleaning materials known as ''Wyandotte Cleaning Specialties.''

In Attendance: B. N. Goodell and E. K. White.

Forging-Stamping-Heat Treating, Pittsburgh. Section A, Booth 35.

Exhibiting: ''Forging-Stamping-Heat Treating,'' published by the Andresen Company, Inc., Pittsburgh. This booth will be fitted up as a rest room where those attending the Convention are invited to make their headquarters. A number of publications devoted to the interests of the iron and steel industry will be on exhibit, including ''Blast Furnace and Steel Plant''; ''Directory of iron and steel, forging, heat treating and stamping plants.''

In Attendance: D. L. Mathias and R. E. Powell.

Ganschow Co., **Wm., Chicago.** Section A, Booth 49.

Exhibiting: Ganschow Speed transformers, types ''A,'' ''B'' and ''C.'' Worm-gear drives. Commercial line of gears and heat treated gears.

In Attendance: A. F. Boissoneau.

Gathmann Engineering Co., Baltimore. Section B, Booth 104.

Exhibiting: Quality steel ingots split open for inspection; ingot molds for producing sound steel ingots; refractory ingot mold tops or sinkheads. Literature setting forth fundamentals essential to improved quality steel production.

In Attendance: Emil Gathmann, George A. Dornin and Mark Gathmann.

General **Alloys Co., Boston.** Section A, Booths 12 and 22.

Exhibiting (in operation): Q-ALLOY castings in service in temperatures up to 2300 degrees Fahr.; Q-ALLOY carburizing boxes; cyanide and lead pots; retorts; muffles; glass dies; conveyor chains; enamel burning racks; ore roasting furnace parts; oil-still parts; cyanide dipping baskets; sheet and cast pans and trays; hearth plates and a large assortment of miscellaneous Q-ALLOY castings, covering the entire heat treating field. Welding of Q-ALLOY will be demonstrated.

In Attendance: H. H. Harris, E. P. Van Stone, W. K. Leach, A. L. Grinell, A. D. Heath, J. J. Donovan and L. J. McCarty.

General **Electric Co., Schenectady, N. Y.** Section B, Booths 90 and 91.

Exhibiting (in operation): Three electric furnaces for heat treating of steel. A small display of immersion units and space heaters.

In Attendance: D. G. Brokaw, L. A. McKenney, L. C. Rossear, J. F. McFarlane, C. L. Ipsen, A. N. Otis, E. F. Collins, W. A. Gluesing and L. W. Shugg.

General **Furnace Co., Philadelphia.** Section B, Booth 109.

Exhibiting (in operation): Continuous electric heat treating furnace (15x4x6 feet).

In Attendance: Horace Drever, Frank Hodson and G. C. Garland.

General **Welding and Equipment Co., Boston.** Section B, Booth 149.

Exhibiting (in operation): An automatic shape-cutting machine with a cutting range of 12x3 feet. This machine is built for cutting heavy machine parts, such as connecting rods, side rods, crankshafts, frames, rudder posts, etc. A still larger machine will be in operation. An

automatic circular plate cutting machine for cutting large discs, rings, washers, etc. This machine is portable and is set directly in the center of the plate to be cut. There is no limit to the diameters. The company's standard line of welding and cutting equipments will be exhibited.

In Attendance: Dr. A. Krebs, Thomas F. Stoddard, Daniel A. Lee, Carlos Krebs, (Miss) M. M. Krebs, J. J. Lee, R. B. Guptill and Arnold White.

Geometric Tool Co., New Haven, Conn. Section C, Booth 208.

Exhibiting (partly in operation): Self-opening and adjustable die heads; self-opening and adjustable rotary die heads and solid adjustable die heads. Adjustable collapsing taps; adjustable collapsing rotary taps and solid adjustable taps. Geometric chaser grinder. Geometric threading machine. Adjustable hollow milling tools. Jarvis high-speed tapping devices. Jarvis friction drive tapping device. Jarvis quick change chucks and collets. Jarvis self-opening stud setters. Specimen threads. Photographs.

In Attendance: G. A. Denison, sales manager, G. T. Case, F. W. Gowrie, J. E. Bullock, E. L. Wood, F. A. Barker.

Gisholt Machine Co., Madison, Wis. Section C, Booth 197.

Exhibiting (in operation): Precision balancing machine for rotative parts. Also a running test stand to show the effects of unbalance on rotating part. Also photos of complete line of machinery and tools.

In Attendance: E. S. Chapman, F. M. Nelson, Z. E. Thomas and R. D. Heflin.

Goddard and Goddard Co., Detroit. Section B, Booth 167.

Exhibiting: Standard and special milling cutters. Railroad channelling, slabbing cutters, helical mills and reamers.

In Attendance: A. N. Goddard, president; C. H. Wallace, special railroad demonstrator, and Dix Proctor of the New York office.

Goss and De Leeuw Machine Co., New Britain, Conn. Section C, Booth 221.

Exhibiting (in operation): A four-spindle automatic chucking machine.

In Attendance: E. H. Peck, J. J. Spring and S. T. Goss.

Gould and Eberhardt, Inc., Newark, N. J. Section C, Booth 221.

Exhibiting (in operation): A 32-inch "Invincible Shaper" with 12 new features. Some of them being: Centralized multiple gravity oiling system for lubricating all main internal bearings, including pulley bearing. A simple and efficient lock for tool head slide gear-shift lever for shifting gears in speed case, has been moved to new convenient location at top of case. Ram handle made of drop forging. A sheet metal guard over the cross-rail with provision to prevent chips from getting under and in back of the slide. Oil wipers are provided on crosshead bearings to keep same clean. The movable vise jaw now has solid top providing ample surface for using surface pointers. An oil filler pipe in gear case, which also indicates proper oil level. A new effective plate clutch with quick acting brake. A No. 16 H. S. manufacturing hobbing machine with slight swivel to cutter spindle for handling a diversified range of spur gears only within the capacity of the machine. All machines motor driven.

In Attendance: A. Miller, H. W. Jacobson and F. G. Eberhardt.

Gunn Manufacturing Co., Boston. Section B, Booth 143.

Exhibiting: Gunn hose clamp tool.

In Attendance: R. N. Gunn, president, and others.

Hagan Co., George J., Pittsburgh. Section B, Booth 108.

Exhibiting (in operation): A new and improved type of tool room furnace—electrically heated and automatically controlled. Complete photographs and descriptions of installations of furnace equipment heated by oil, gas, coal and electricity. Complete display of oil and gas burning equipment for all industrial heating purposes.

In Attendance: J. E. Randall, P. A. Meyer, G. T. Thatcher, R. E. Talley, C. F. Cone, R. L. Corbett and A. D. Dauch.

Halcomb Steel Co., Syracuse, N. Y. Section A, Booth 50.

Exhibiting: Various tools made from different grades of tool steel and automobile parts made from HALECTRALLOY brand, alloy steels and heat and rust resisting alloys.

In Attendance: H. J. Stagg, manager; M. P. Spencer, assistant sales manager; S. C. Spalding, metallurgist; R. Atkinson, J. T. Leyden, L. D. Hawkridge, J. F. Kirwan, E. F. Talmage, H. D. Evans, J. H. Hinkley, A. Schroeder, F. W. Ross, E. L. Reed, J. E. McGregor and T. F. Wood.

Hauck Mfg. Co., Brooklyn, N. Y. Section A, Booth 54.

Exhibiting: Hauck Venturi low pressure burners in four different sizes and Hauck Venturi high pressure burners (steam or compressed air) of different sizes.

In Attendance: F. J. Schwenk, sales manager, Frank Thomson, New England district representative, Julius Escheman, Buffalo district representative, and A. F. Schumann, Philadelphia district representative.

Hayes, C. I., Providence, R. I. Section B, Booth 102.

Exhibiting (in operation): Electric furnace (annealing, hardening, etc.); electric temper drawing furnace; automatic temperature control and safety control for electric furnace to prevent over-heating and accidental burnout.

In Attendance: C. I. Hayes, chief engineer; J. E. Hines, sales manager, and A. E. Bernier.

Heald Machine Co., Worcester, Mass.. Section C, Booth 209.

Exhibiting (in operation): Cylinder grinding machine; internal grinding machine; automatic rotary surface grinding machine and magnetic chucks.

In Attendance: R. A. Heald and Robert M. Lippard.

Heim Grinder Co., Danbury, Conn. Section C, Booth 251.

Exhibiting (in operation): Heim centerless grinding machine. Also samples of work ground on the centerless machine.

In Attendance: Robert Krametz.

Hendey Machine Co., Torrington, Conn. Section C, Booth 241.

Exhibiting (in operation): Hendey 14"x6′ model E. B. M. motor-driven engine lathe. Hendey 24-inch motor-driven crank shaper. Hendey No. 2 all-geared universal milling machine, motor-driven.

In Attendance: A. H. Hall and E. W. Bersler.

Heppenstall Forge and Knife Co., Pittsburgh. Section A, Booth 57.

Exhibiting: Various drop forgings, which have been manufactured from the company's die blocks and which forgings are considered more or less perfect. Attached to each forging exhibited will be a card indi-

cating the grade of die block from which forging was made and also
the approximate number of forgings made from these blocks.

In Attendance: C. W. Heppenstall, A. J. Porter, Jr., C. J. Sauer, H. P.
Jones, A. L. Wurster and Floyd Rose.

High Speed Hammer Co., Rochester, N. Y. Section C, Booth 204.

Exhibiting (in operation): Full line of High Speed riveting hammers,
and model ''E'' High Speed sensitive drill press. Three sizes of
hammers, that is No. 1—AA, 3—A heavy duty, and 6—b Bolster type,
practically demonstrated.

In Attendance: E. F. Meyering, H. A. Moore and H. C. LeVine.

Hoskins Manufacturing Co., Detroit. Section B, Booth 115.

Exhibiting (in operation): An electric heat-treating furnace, having
CAST heating units of Chromel, equipped with automatic temperature
control pyrometer.

In Attendance: Chas. S. Kinnison, G. L. Price, W. D. Little and W. A.
Gatward.

Houghton and Co., E. F., Philadelphia. Section B, Booths 119 and 120.

Exhibiting: Heat treating materials: VIM leather belting and VIM
leather packings.

In Attendance: R. K. Gurney, R. F. Smith, W. A. Buechner, H. E. Cress-
man and J. Coleman Bentley.

Hunter Saw and Machine Co., Pittsburgh. Section B, Booth 131A.

Exhibiting (partly in operation): Inserted tooth saws; solid saws for
all makes of metal cutting sawing machines; hot saws; tube saws;
high-speed metal cut-off saws and friction discs. Saw sharpening and
beveling machines. Inserted saw grinders. Inserted tooth setting-up
device. Device for dressing friction discs. Circular shear knives. Ro-
tary pipe cutters. Circular paper and cigarette knives; circular cork
knives and circular rubber knives. Various hardened steel specialties.
Pneumatic hammer rivet sets and chisel blanks.

In Attendance: H. S. Hunter, F. A. Hunter and Carl Schnubel.

Illingworth Steel Co., Philadelphia. Section B, Booth 118.

Exhibiting: Samples of rolled steel; heat treated and finished dies.
Manufactured products resulting from these materials.

In Attendance: James Chadderton, Boston district; A. W. F. Green,
metallurgist.

Industrial Gas Equipment Co., New Haven, Conn. Section A, Booth 5.

Exhibiting (in operation): Reeves Gas-Air Pre-Mixing installation.
Reeves Venturi inspirators. Furnaces. Special burners.

In Attendance: F. I. Newton, David Dibbell and Charles A. Drum.

International Nickel Co., New York City. Section A, Booths 13 and 23.

Exhibiting: Samples of nickel steel and nickel steel products for various
industrial uses.

In Attendance: Dr. P. D. Merica, Charles McKnight, Jr., T. H. Wicken-
den and L. Muller-Thym.

Iron Age Publishing Co., New York City. Section A, Booth 60.

Exhibiting: Publication, ''Iron Age.''

In Attendance: F. J. Frank, C. S. Baur, F. S. Wayne, A. L. Marsh, C.
Lundberg, W. C. Sweetser, B. L. Herman, D. C. Warren, H. E. Barr,
Emerson Findley, H. B. Todd, O. B. Bergersen, Rodney Derby, Robert

E. Baur, E. Sinnock, F. W. Schultz, C. L. Rice, W. B. Robinson, B. H. Hayes, C. E. Lachaussee, A. H. Dix, E. A. Trumpbour, D. G. Gardner, A. I. Findley, W. W. Macon, Gerard Frazar, E. F. Cone, R. E. Miller, S. G. Koon and C. E. Wright.

Jessop & Sons, Inc., William, Boston. Section B, Booth 171-B. Booth will be used for reception.

In Attendance: F. C. A. H. Lantsberry, Sheffield, England; J. T. Wood, New York; J. M. Curley, Boston.

Jones and Lamson Machine Co., Springfield, Vt. Section C, Booths 211 and 217.

Exhibition (in operation): Hartness flat turret lathe (15-inch chucking machine). Two Fay automatic lathes. Hartness screw thread comparator. Hartness automatic dies. Flanders ground thread taps.

In Attendance: H. S. Beal, assistant general manager; B. L. Billings, sales representative for New England; and J. L. Lovely, chief engineer, Fay Automatic Lathe Division.

Jones and Laughlin Steel Corporation, Pittsburgh. Section A, Booth 44.

Exhibiting: Various steel products of interest to those in attendance at this Convention.

In Attendance: A. A. Wagner and A. B. Marble and others.

Kardex Co., Tonawanda, N. Y. Section B, Booth 174.

Exhibiting: Kardex visible records and filing systems.

In Attendance: C. F. McKee, Boston district manager.

Keller Mechanical Engineering Corp., Brooklyn, N. Y. Section C, Booth 221.

Exhibiting (in operation): Keller type E-5 automatic die-sinking machine. Machine is electrically controlled and duplicates in the die block, the form of a soft master or pattern. Keller type R-6 Universal cutter and radius grinder. Keller type BK flexible shaft grinder on bench. Keller type BK-2 flexible shaft grinder on roller floor stand. Samples of dies, molds, etc., cut on Keller machines, and the work produced by these dies.

In Attendance: S. A. Keller, Jules Dierckx, Henry Schreiber, Charles A. Mertens, M. Mayer and C. J. Priebe.

Keystone Lubricating Co., Philadelphia. Section A, Booth 24.

Exhibiting (in operation): Keystone Safety Lubricating System, both hand operated and with the Keystone Automatic Convertor Cup. This method of lubrication is a real necessity for the safe, economical and efficient operation of cranes, conveyors and ore bridges, as well as for various smaller production units.

In Attendance: H. A. Buzby, L. A. Webster, G. W. Hall, C. O. Norstrum, C. H. Stone, H. J. Kass, C. H. Tholl, F. D. Street.

King Refractories Co., Inc., Buffalo. Section A, Booth 38.

Exhibiting (in operation): A Bulletin machine. High Temperature cements. "MONO" baffles and Fire brick.

In Attendance: S. C. Smith, F. B. Lythgoe and M. F. Tenny.

Kobert Machine Co., Wooster, Ohio. Section C, Booth 221.

Exhibiting (in operation): Kobert electrical rivetting machines.

In Attendance: F. C. Kobert.

Leeds and Northrup Co., Philadelphia. Section B, Booths 101 and 114.

Exhibiting (in operation): Potentiometer pyrometers, including indicating, recording and controling equipment. Hump electric hardening furnaces and electric drawing furnaces. Also some special demonstrations pertaining to heat treatment.

In Attendance: Henry Brewer, G. W. Tall, Jr., E. B. Estabrook, Oscar Brewer, T. C. Smith, W. A. Lane, Jordan Korp, J. W. Harsch, H. N. MacMichael, E. H. Carlson and P. H. Taylor.

Leitz, Inc., E., New York City. Section A, Booth 56.

Exhibiting (in operation): Latest design micro-metallograph, which has recently been placed upon the market. This instrument embodies numerous new features not found in any type of instrument previously placed upon the market, and it has received the highest recommendation from all authorities who have had the opportunity of examining and using the instrument. New grinding and polishing machines for metal specimens, metallurgical microscopes and photographic apparatus of simple design, as well as a complete assortment of accessories used in connection with metallurgical work. The ore-dressing microscope, which has recently been placed upon the market, will be demonstrated. Other microscopical equipments shall be placed on display.

In Attendance: A. Bader, A. Buehler and Mr. Zieler.

Lewis-Shepard Co., Boston. Section B, Booth 116.

Exhibiting (partly in operation): Jacklift and singlelift elevating trucks. Lewis-Shepard steel leg platforms and Lewis-Shepard stackers or portable elevators.

In Attendance: G. E. Squier, sales manager.

Lodge and Shipley Machine Tool Co., Cincinnati. Section C, Booth 221.

Exhibiting (in operation): ''Duomatic'' lathe for the advantageous use of multiple tooling in turning and facing operations particularly adapted to quantity production of lathe work held between centers, on an arbor, or in suitable holding fixtures. The cycle of operation is completely automatic, including the locating of diameters and lengths on the work piece. It is an extremely heavy and rugged machine, designed to withstand the heavy strains imposed upon it in the automobile and allied industries. Latest type of 12-inch lathes.

In Attendance: Fred Albrecht, sales manager, and Earl M. Wagner, Eastern representative.

Ludlum Steel Co., Watervliet, N. Y. Section B, Booths 148 and 160.

Exhibiting: Tool steel and special alloy steels, high-speed steel and noncorrosive and heat resisting steels, showing shapes, sizes and conditions of treatment in which they are supplied, together with interesting steps in their manufacture. There will also be an extensive exhibit of tools and parts, showing the wide range of applications of these special steels and the constantly expanding field for stable surface material.

In Attendance: V. S. Yarnell, assistant to the president; W. H. Vrooman, assistant manager of sales; C. B. Templeton, Jr., sales department; A. A. Colebrook, New York manager of sales; G. F. Wilson, Philadel-

phia manager of sales; E. R. S. Reeder, Boston manager of sales;
S. T. Pearsons, W. L. Weaver, Albany territory; J. E. Moyer, Millers-
burg, Pa., J. E. Polhemus, Detroit manager of sales; W. A. Edwards,
Chicago manager of sales, and T. C. Sherman, Cleveland manager of
sales.

Lynd-Farquhar Co., Boston. Section C, Booth 245.

Exhibiting: Machine tools made by the following firms:
American Tool Works, Cincinnati
Chas. G. Allen Co., Barre, Mass..
Cochran-Bly Co., Rochester, N. Y.
Rockford Milling Machine Co., Rockford.
A. C. Campbell Co., Inc., Bridgeport, Conn.
Monarch Machine Tool Co., Sidney, Ohio
Wilmarth-Marmon Co., Grand Rapids, Mich.
Heim Grinder Co., Danbury, Conn.
G. D. Blakeslee Co., Chicago.

In Attendance: E. D. Crockett, B. H. Shaw, James E. McCarthy, H. A.
Prentiss and various other representatives given under the individual
listing of the above companies.

McDonald and Co., P. F., Boston. Section B, Booth 107.

Exhibiting: Macco steels. Macco Fagersta Swedish tool steel, carbon,
chrome tungsten, vanadium, oil-hardening non-shrinkable, spindle steel,
cutlery sheets, die-blocks and special sections. Macco Sandviken
Swedish cold rolled French-finished, annealed tool steel, blue-tempered,
straw-tempered and bright-tempered. Thickness-gauge steel from .0015
inches thick to .032 inches. Specialty strip steels for all requirements.
Macco Laxa genuine Swedish iron, bars and sheets also cold drawn
for electrical requirements. Page-Armco welding rods and electrodes
for gas and electric welding. G-E welding electrodes especially for cast
iron welding by electric process.

In Attendance: M. J. McDonald, sales manager; N. L. Schuver, J. W.
Morrissey, I. L. Bambrick and C. W. Greene.

Midvale Company, Nicetown, Philadelphia. Section B, Booth 141.

Exhibiting: Hardened and ground chrome steel rolls. Finish-ground
tool steel bars. Shock resisting alloy steels. Various cutters manufac-
tured from Midvale extra high-speed drill steel.

In Attendance: Stuart Hazlewood, vice-president; H. E. Rowe, in charge
of exhibit; W. A. Miller, New York district manager of sales; W. B.
Smyth, Cleveland district manager of sales; T. G. Besom, New Haven;
C. M. Smith, Boston; J. W. Walsh, Philadelphia, and Henry Ziesing,
Philadelphia.

Moline Tool Co., Moline, Ill.. Section C, Booth 221.

Exhibiting (in operation): Multiple straight line drilling machine, drill-
ing work for textile machine manufacture.

In Attendance: W. P. Hunt and H. D. Gentry.

Monarch Machine Tool Co., Sydney, Ohio. Section C, Booth 245A.

Exhibiting (in operation): A 16-inch by 6-foot Monarch quick-change
gear lathe equipped with 8-speed geared headstock arranged for motor
drive. An 18-inch by 6-foot Monarch geared-head manufacturing lathe
having 4-speed head, 4 changes of feed, designed for machining large
quantities of duplicate parts. A 26-inch Whipp open-side crank shaper-
planer arranged for motor drive.

In Attendance: W. E. Whipp, general manager and secretary-treasurer.

Morse Twist Drill and Machine Co., New Bedford, Mass. Section B, Booth 140.

Exhibiting (in operation): Drills, reamers, cutters, taps, dies, arbors, chucks, mandrels, sockets, sleeves and taper pins.

In Attendance: W. T. Read, vice-president.

National Automatic Tool Co., Richmond, Ind. Section C, Booth 221.

Exhibiting (in operation): NATCO multiple spindle-drilling and tapping machinery. NATCO universal joints. NATCO tap holders. NATCO tool holders. NATCO straight-shank drill holders. NATCO drill heads.

In Attendance: F. D. Shriver, sales representative; H. A. Fuller, service representative, and E. D. Frank, sales manager.

National Electric Light Association, Boston Section B, Booth 93.

Exhibiting: Photographs and engineering data on industrial heating installations. Those in attendance in booth will endeavor to give information and advice on industrial heating installations.

In Attendance: H. W. Derry, Hartford Electric Light Co.; R. S. Moore, J. L. Faden, G. C. Polsen, G. G. Kearful, S. Chapman, J. W. Wattles and T. I. Donahue, all of Edison Electric Illuminating Company of Boston; E. D. Learned, Worcester Electric Light Co.; F. K. Simmons, Blackstone-Valley Electric Co., Pawtucket, R. I.; H. Southworth, Narragansett Electric Light Co.; P. R. Moody, W. H. Sammis and T. D. Bond of the C. H. Tenney and Co., Boston; W. R. McKeogh, Gardner Electric Light Co.; G. F. Parsons, C. D. Parker and Co., Boston; H. E. Stearns, Cambridge Electric Light Co.; A. C. Gowing, Union Electric and Power Co., Franklin, Mass.; L. V. Clark, American Light and Power Co.; J. H. Jackson, Keene Gas and Electric Co.; H. E. Duren, Springfield Electric Light Co.; F. S. Root, Fall River Electric Light Co., and H. Burgy, Jr., Cumberland County Light and Power Co., Portland.

National Twist Drill and Tool Co., Detroit. Section A, Booth 46.

Exhibiting: Complete line of twist drills, reamers, hobs, cutters, counterbores, combined drill and countersinks and special tools. Also "7716" drills and parabolic milling cutters.

In Attendance: H. Butler, assistant sales manager.

New Britain Machine Co., New Britain, Conn. Section C, Booth 220.

Exhibiting (in operation): A No. 454 New Britain New-Matic chucking machine.

In Attendance: H. H. Pease, president; R. S. Brown, secretary and chief engineer; E. L. Steinle, manager, machinery sales; R. T. Frisbie, manager, screw products department; Arno Schubert, F. R. Downs, New England representative; C. A. Doherty, demonstrator, and R. Hulbert, purchasing agent.

New England Annealing and Tool Co., South Boston. Section A, Booth 48.

Exhibiting: Samples of drop forgings and specimens of heat treating.

In Attendance: Z. L. Sault and R. G. Sault.

New England Association of Gas Engineers, Boston. Section B, Booths 137 and 147.

Exhibiting: Photographs and descriptive matter regarding the gas industry in general and the application to gas for steel treating.

In attendance: P. J. LaFore and J. L. Tudbury.

Norton Company, Worcester, Mass. Section B, Booth 170.

Exhibiting: Alundum and crystolon grinding wheels. Norton refractory ware. Norton floors.

In Attendance: C. W. Saxe, Robt. Kirkpatrick, R. P. Capron and J. S. Rose.

Nuttall Co., R. D., Pittsburgh. Section B, Booth 142.

Exhibiting: Various types of hardened gears, and especially gearing and other wearable machine parts that have been hardened and toughened by the company's BP process.

In Attendance: R. F. Fiske, J. E. Mullen and W. H. Phillips.

Ohio Machine Tool Co., Kenton, Ohio. Section C, Booth 213.

Exhibiting (in operation): A 36-inch OHIO dreadnaught shaper.

In Attendance: C. C. Swift and L. H. Peters.

Ohio Steel Foundry Co., Springfield, Ohio. Section B, Booth 96.

Exhibiting: FAHRITE castings for resistance to heat and corrosion. Also a small electric furnace will be in operation.

In Attendance: T. H. Harvey, vice-president; H. G. Shook, manager, alloy division; F. D. Rice and E. L. Malone, Philadelphia representatives, and Edwin R. Knapp, New York representative.

O. K. Tool Company, Shelton, Conn. Section C, Booth 198.

Exhibiting (in operation): Complete line of products, consisting of system of holders and tools for lathes, planers, shapers, boring mills and automatic and special machines. Also the O. K. inserted tool milling cutters, including inserted tooth sectional hobs for cutting gears. Grinding machine in operation especially equipped for using O. K. tool blocks for grinding tools.

In Attendance: G. W. Conklin, Frederick Schroeder and H. L. Taylor.

Olsen Testing Machine Co., Tinius, Philadelphia. Section A, Booth 64.

Exhibiting (in operation): Various types of testing machines, including an Olsen universal testing machine with various attachments and tools for conducting numerous special tests. Various types of Brinell hardness and Olsen Last-Word hardness testers, as well as the Herbert pendulum hardness tester. Olsen-McAdam alternate-torsion tesing machine; also special new equipment for tension and compression testing of cement and ceramic materials, as well as of testing paper, etc. Ductility testing machines for sheet metal, and extensometers for testing purposes. Also an Olsen-Lundgren balancing scale and an Olsen Carwen static-dynamic balancing machine and equipment for weighing connecting rods.

In Attendance: R. B. Lewis and T. Y. Olsen.

Oxweld Acetlyene Co., New York City. Section A, Booth 65.

Exhibiting: Welding steel boiler plate, cutting it into test pieces and pulling these test pieces in a standard Olsen testing machine, thus demonstrating, by 15-minute tests throughout the week, the uniformity and dependability of the oxyacetylene weld.

In Attendance: Sidney Wade, publicity department.

Pangborn Corporation, Hagerstown, Md. Section B, Booths 151 and 152, 163 and 164.

Exhibiting (in operation): Sand-Blast Barrel, Rotary table and small

cabinet types; Cloth Screen Dust Arrestor and Exhauster, showing how sand blast equipment can be operated, ventilated and dust entirely suppressed, allowing discharge of the cleaned air into the shop atmosphere. Quantities of various kinds of steel treated materials for continuous operation of the sand blast units. Samples of steel shot and angular steel grit with practical demonstration of their uses in sand blasting, also samples of interesting and intricate steel treated work, before and after sand blasting, from manufacturers in various parts of the country.

In Attendance: T. W. Pangborn, president; H. D. Gates, sales manager; G. A. Cooley, district sales engineer; C. T. Bird, district sales engineer; G. H. Kahn and H. M. Ream.

Peerless Machine Co., Racine, Wis. Section C, Booth 248.

Exhibiting (in operation): One 13x16 inch Peerless gap saw; one 13x13 inch Universal shaping saw and one 6x6 inch Universal shaping saw. Demonstrations on actual work, cutting various materials.

In Attendance: A. H. Goetz and I. M. Ward.

Pennsylvania Pump and Compressor Co., Easton, Pa. Section B, Booth 153.

Exhibiting (in operation): A 9x8 inch class 3A Pennsylvania air compressor direct-connected to synchronous motor.

In Attendance: G. S. Githens, Boston.

Penton Publishing Co., Cleveland. Section A, Booth 33.

Exhibiting: Books and publications.

In Attendance: John Henry, A. M. Pulaski, E. F. Ross, H. R. Simonds and R. C. Coursen.

Pittsburgh Crucible Steel Co., Pittsburgh. Section A, Booth 51.

Exhibiting: Parts used in automobile manufacture made from Pittsburgh Crucible Steel Company's steel; also exhibition showing various stages of the manufacture of basic open hearth alloy and high grade carbon steel.

In Attendance: S. P. Broome, Philadelphia; D. G. Campbell, Pittsburgh; R. K. Carson, New York; F. T. Conner, Chicago; J. T. Critchlow, Detroit; H. T. Harrison, Buffalo; R. N. Keeney, Pittsburgh; W. I. McInerney, Pittsburgh; K. E. Porter, Cleveland; E. T. Walton, Detroit, and S. D. and W. W. Williams of Pittsburgh.

Potter and Johnston Machine Co., Pawtucket, R. I. Section C, Booth 242.

Exhibiting (in operation): A 6C automatic chucking and turning machine. A 2M automatic milling machine and a 24-inch universal shaping machine.

In Attendance: Norman R. Earle and others.

Pratt and Whitney Co., Hartford. Section C, Booth 196.

Exhibiting (in operation): Thirteen by thirty-two inch Model B Lathe, motor-driven. Showcase of complete line of gauges and small tools. Fractured and defective small tools.

In Attendance: Marcus Chase; T. Boyd and M. S. Bradley of Boston; A. H. d'Arcambal, small tool department, Hartford, and A. E. R. Turner of machinery department, Hartford.

Prentiss Co., Henry, New York City. Section C, Booths 221 to 227 and 228 to 235.

Exhibiting: Machines and machine tools manufactured by the following firms:
Keller Mechanical Engr. Corp., Brooklyn, N. Y.
O. S. Walker Co., Worcester, Mass.
V and O Press Co., Hudson, N. Y.
Baker .Brothers, Toledo, Ohio
Blanchard Machine Tool Co., Cambridge, Mass.
Avey Drilling Machine Tool Co. Cambridge, Mass.
Gould and Eberhardt, Newark, N. J.
Cincinnati Acme Co., Cincinnati
Cincinnati Planer Co., Cincinnati
Cincinnati Bickford Machine Tool Co., Cincinnati
Cincinnati Milling Machine Co., Cincinnati
Moline Tool Co., Moline, Ill.
Henry G. Thompson Co., New Haven, Conn.
Lodge and Shipley Machine Co., Cincinnati

In Attendance: W. F. McCarthy and various other representatives given under the individual listing of the above companies.

Racine Tool and Machine Co., Racine, Wis. Section C, Booth 215.

Exhibiting (in operation): Racine high-speed metal cutting machine, 4x4 to 12x12 inches. Racine duplex band-saw machines.

In Attendance: J. M. Jones, manager; Wm. C. Reinhardt, superintendent, and possibly others.

Republic Flow Meters Co., Chicago. Section A, Booth 26.

Exhibiting (in operation): Complete indicating and recording pyrometer equipment with thermocouples, protecting tubes, etc. Complete line of power plant instruments, consisting of CO_2 indicators and recorders, draft indicators and recorders; steam, gas, oil and water flow-meters, flue gas hand analyzers.

In Attendance: C. C. McDermott, Jack Morehouse, manager of Boston office, and J. D. Cunningham, president.

Rivett Lathe and Grinder Corp., Boston. Section C, Booth 207.

Exhibiting (in operation): A No. 103 internal grinder, motor driven, grinding holes in standard collets. No. 106 internal grinder, motor driven, grinding holes in standard collets. No. 505 plain precision lathe. No. 608 back-geared precision bench-lathe mounted on oak cabinet with gear box, spiral and traverse milling attachments, milling special spiral reamers. "Camel" oil cups. Rivett improved thread tool and cutters. Rivett quality collets.

In Attendance: E. P. MacCannell and A. L. Hathorne.

Rockford Milling Machine Co., Rockford, Ill. Section C, Booth 244.

Exhibiting (in operation): Sundstrand 8-inch Stub Lathe, tooled complete for making flange yokes. Machine will be arranged for motor drive, and a demonstrator will be present to keep machine in constant operation machining the flanges. A Rockford No. 3 Heavy Universal Single Pulley Drive Milling Machine with Barber-Colman cutter, will also be on exhibition. This will be arranged for motor drive in actual operation, milling cast iron slabs.

In Attendance: D. B. Burleigh.

Rockwell Co., W. S., New York City. Section A, Booth 30.

Exhibiting: Models of operating furnaces.

In Attendance: J. N. Voltmann and C. D. Barnhart.

Rodman Chemical Co., Rodman, Pa. Section A, Booth 34.

Exhibiting: Case hardening or carburizing compounds; quenching oils; tempering oils and luting compound.

In Attendance: Hugh Rodman, general manager; S. P. Rockwell and W. D. Fuller, New England representatives, and Gordon A. Webb, Detroit representative.

Roessler and Hasslacher Chemical Co., New York. Section A, Booth 58.

Exhibiting: Samples of copper plating for related uses. Collection of case hardening compounds.

In Attendance: Charles H. Procter, New York; William Gager, Perth Amboy; W. J. Schneider, New York; and Boston representatives.

Ryan and Co., F. J., Philadelphia. Section A, Booth 17.

Exhibiting (in operation): High speed tool hardening furnace equipped with Ryan-Austin automatic control.

In Attendance: F. J. Ryan, G. F. Beach, F. A. Hall, T. B. Bechtel, G. R. Coats and E. L. Willson.

Seneca Falls Machine Co., Seneca Falls, N. Y. Section C, Booth 250.

Exhibiting: Short cut production lathes.

In Attendance: E. R. Smith.

Shore Instrument Co., Jamaica, N. Y. Section B, Booth 169.

Exhibiting (in operation): C-1 Model Scleroscope (bulb type) electrically operated to facilitate quantity production; D Model Scleroscope (recording type) improved. A and B Model Pyroscopes optical instruments, range 200 degrees Fahr., to 3,000 degrees Fahr. Durometer and Elastometer for testing pliable material. Localhard and Localease for selective hardening. Accessories and fixtures.

In Attendance: F. G. Kendall and assistant.

Simonds Saw and Steel Co., Fitchburg, Mass. Section B, Booths 127 and 128.

Exhibiting: Metal cutting saws, files, hack saws, carbon and high speed steel sheets and bars.

In Attendance: H. B. McDonald, C. R. Paffenbach and C. W. McKay.

Skinner Chuck Co., New Britain, Conn. Section B, Booth 121.

Exhibiting: Skinner chucks.

In Attendance: P. K. Rogers, vice-president.

Sly Manufacturing Co., W. W., Cleveland. Section B, Booths 155 and 156.

Exhibiting (in operation): Two Universal Slyblast mills (20x20 inches inside diameter. A Slyblast pressure tank and a 30/48 Slyblast cabinet.

In Attendance: F. A. Ebeling, sales manager; D. L. Harris, Eastern representative, and D. C. Gilchrist, advertising manager.

Spencer Turbine Co., Hartford, Conn. Section A, Booth 7.

Exhibiting (in operation): Spencer Turbo compressors for supplying air

for oil and gas-burning industrial furnaces. These machines will be
of the multi-stage, low velocity, turbine type. One catalogue No. 1515
outfit with a capacity of 1350 c. f. m. at 1½ pounds pressure; one
No. 1505 machine with a capacity of 450 c. f. m. at 1½ pounds press-
ure, and one No. 1001 machine with a capacity of 125 c. f. m. at 1
pound pressure. Machine No. 1515 will supply air for the industrial
furnaces on exhibit.

In Attendance: S. E. Phillips, secretary; H. M. Grossman, sales engineer,
and O. J. Dingee, sales engineer.

Steel City Testing Laboratory, Detroit. Section B, Booth 171A.

Exhibiting: Power and hand Brinell machines.

In Attendance: H. A. Weaver.

Stromberg Electric Co., Chicago. Section B, Booth 133.

Exhibiting: Various methods of Stromberg process tuning and signaling
machines.

In Attendance: E. E. Spencer, R. L. Harvey and V. R. Dittman.

Surface Combustion Co., New York City. Section A, Booth 16.

Exhibiting (in operation): Automatic heat treating furnace; new type
of recuperative furnace. Display of the ''Blue Line'' stock furnaces.

In Attendance: F. J. Evans, New York City; C. B. Philips, Toledo, Ohio;
C. H. Cummings, Industrial Appliance Company of New England, Boston;
and M. K. Epstein, Heat Treating Equipment and Supply Co., Hartford.

Swedish Crucible Steel Co., Detroit. Section A, Booth 1.

Exhibiting: Nickel alloy carbonizing boxes, retorts, tubes, furnace rails,
furnace racks, etc. High nickel-chromium alloys. Special heat re-
sisting steel-cyanide and lead pots, carbonizing boxes and miscellaneous
castings.

In Attendance: S. R. Allen and H. K. Nixon.

Tacony Steel Co., Philadelphia. Section B, Booth 162.

Exhibiting: Alloy bar steel, forgings, die blocks, piston rods and trim-
mer steel.

In Attendance: H. A. Baxter, vice-president, and C. G. Fallon, Boston dis-
trict sales manager.

Thomson Electric Welding Co., Lynn, Mass. Section B, Booth 97.

Exhibiting (in operation): Butt welder—electrically welding steel bars.
Spot welder—electrically welding steel sheets.

In Attendance: M. G. Littlefield, L. S. Taylor and R. M. Taylor.

Thompson and Son Co., Henry G., New Haven, Conn. Section C, Booth 221.

Exhibiting (in operation): A new ''Milband'' cutting-off machine.

In Attendance: Thomas A. Hyde and Wm. Neville.

Union Twist Drill Company, Athol, Mass. Section C, Booth 216.

Exhibiting: Milling cutters, metal slitting saws, hobs, special cutters,
reamers, twist drills, taps, dies, tap wrenches and die stocks. One
revolving case driven by 1/10 H. P. motor, 110 volts, 60 cycle.

In Attendance: J. H. Horigan; J. W. Rathbun, G. F. Holland, W. E. Hors-
field and L. H. Lathe.

United Alloy Steel Co., Canton, Ohio. Section A, Booths 31 and 32.

Exhibiting: Articles and data in connection with the application of open hearth and electric furnace alloy steels.

In Attendance: H. H. Pleasance, vice-president, F. W. Krebs, J. G. Bell and A. W. Minuse.

V and O Press Company, Hudson, N. Y. Section C, Booth 221.

Exhibiting (in operation): A No. 3 standard inclinable press equipped with die and stock reel. A No. 201½ combination threading and trimming machine equipped with chucks for performing threading, trimming and knurling in a single operation. This machine will also be equipped with an automatic chute feed.

In Attendance: F. M. Ironside and probably others.

Vanadium Alloys Steel Co., Latrobe, Pa. Section A, Booth 62.

Exhibiting: Steel samples showing the different stages in processing a bar from the ingot to the finished stock. Finished tools showing the many different uses of tool steels.

In Attendance: J. P. Gill and L. D. Bowman of Latrobe, Pa.; D. A. Black, Boston; E. B. Kitfield, Wallingford, Conn.; R. L. Daull, Cleveland; A. F. MacFarland, Detroit; A. F. Chilcott, Buffalo, N. Y., and J. A. McKay, New York City.

Vanadium Corporation of America, New York City. Section A, Booth 67.

Exhibiting: Attract-O-Scope, showing lantern slides of mining and shipping Vanadium ore in Peru, etc.; also specimens of Vanadium ore and Ferro Vanadium.

In Attendance: M. G. Baker, vice-president; J. A. Miller, Jr., H. T. Chandler and G. L. Norris.

Vulcan Crucible Steel Co., Aliquippa, Pa. Section B, Booth 172.

Exhibiting: Tool steels (high-speed, alloy and carbon), and special steels. Materials used in their manufacture and tools and parts made from them.

In Attendance: S. G. Stafford, president; R. M. Kelso and A. D. Beeken, Jr., Aliquippa, Pa.; A. Hartel, Jr., G. H. Burnett, O. R. Hartel, A. Hartel, III, and Chas. E. Karle, Boston; Leo D. Sullivan, Detroit; T. S. Hanna, New York City, and G. L. Kronfeld, Pittsburgh.

Walcott Lathe Co., Jackson, Mich. Section C, Booth 214.

Exhibiting (in operation): New all-geared head "Low Drive" engine lathe, and model cam turning lathe.

In Attendance: D. G. Kimball, president and general manager, and C. S. Sylvester, factory superintendent, and Boston representative.

Walker Co., Inc., O. S., Worcester, Mass. Section C, Booth 221.

Exhibiting (in operation): A single-stroke surface grinding machine, motor driven. Five magnetic chucks and one set of planer parallels.

In Attendance: Lawrence G. Drury.

Wallace and Sons Mfg. Co., R., Wallingford, Conn. Section B, Booth 173.

Exhibiting: Wallace silver—showing use of stainless steel knife blades in all grades of Wallace cutlery.

In Attendance: H. G. Goodwill, R. G. Hall and possibly others.

Wards' Sons Co., Edgar T., Boston. Section A, Booth 42.

Exhibiting: Cold drawn steel bars; turned and polished shafting; turned and ground shafting; cold rolled strip steel and flat wire; cold drawn seamless steel tubing; tool steels; Swedish tempered and untempered cold rolled steels; drill rods; imported music wires; spring steels of various kinds, Armco iron in sheets and rods and electrical sheets.

In Attendance: John Ward, E. T. Corbus, branch manager; J. A. Parons, W. A. Sandison, W. T. James, M. L. Tebbetts, N. J. P. Helling, W. G. H. Thomson and B. R. Heathcote.

Warner and Swasey Co., Cleveland. Section C, Booth 228 and 236.

Exhibiting (in operation): A 1-A Universal Hollow Hexagon Turret Lathe. This is the first time this machine will have been exhibited. It will be equipped with full chucking equipment and operated on a typical chucking job, showing its possibilities.

In Attendance: E. R. Gardner, manager of New York office; J. A. Craig, service representative, and C. J. Stilwell, domestic sales manager.

Westinghouse Electric and Mfg. Co., East Pittsburgh. Section B, Booths 94 and 95.

Exhibiting (in operation): Several hearth-type electric furnaces; furnace heating units and other equipment of interest. Four hearth-type furnaces will be in operation under automatic control, demonstrating the accuracy with which any desired temperature may be maintained. The furnace heating units are a recent development of the company and have never before been displayed. They will be shown in place on a section of furnace wall.

In Attendance: W. S. Scott; A. T. Ruttencutter; R. M. Keany and P. H. Grunnagle.

Wetherell Brothers Co, Cambridge, Mass. Section B, Booth 154.

Exhibiting: Steel—bars, blocks, shapes, wires, etc. Products made from various special steels sold.

In Attendance: F. A. Wetherell, L. H. Wetherell, L. E. Zurbach, R. A. Johnston, L. R. Quigley, L. T. Perry, A. S. Mahen and W. C. Brooks.

Wheelock, Lovejoy and Co., Inc., Cambridge, Mass. Section A, Booth 27.

Exhibiting: Hy-Ten alloy steels and their application to special parts.

In Attendance: A. O. Fulton, F. H. Lovejoy and S. W. Parker from Cambridge office. Edward C. Bartlett, Cleveland; L. P. Needham, Chicago, and E. P. Gaffney, New York City.

Whitehead Metal Products Co., New York City. Section B, Booth 136.

Exhibiting (in operation): Electric welding machine; Wilson plastic arc—200 amperes; motor generator, single operator with type ''J'' control panel.

In Attendance: Wm. M. Bastable, R. F. Blessington, T. M. Bohen, E. W. Silver and S. Marks.

Wilmarth and Morman Co., Grand Rapids, Mich. Section C, Booth 237.

Exhibiting (in operation): A No. 1 Universal Cutter and Tool Grinder. power-feed, motor-drive, complete with all attachments, 220 volt, single phase, 60 cycle (⅛, ¼ and ½ H. P.). A No. 78 Surface Grinder, arranged for motor-drive, 220 volt, three phase, 60 cycle

(2 H. P.).   A "B" Point Improved NEW YANKEE Drill Grinder, 220 volt, three phase, 60 cycle (2 H. P.).

In Attendance: Arthur Williams.

Wilson-Maeulen Co., New York City. Section B, Booths 129 and 130.

Exhibiting: Rockwell direct reading hardness tester, including new model 4-B of 12-inch capacity. Recording and indicating pyrometer equipment, including new model D tapalog recording pyrometer. Resistance thermometer equipment. New automatic temperature control equipment.

In Attendance: J. E. Heckel, Boston, and others.

Wolff Gas Radiator Co., A. H., New York City. Section A, Booth 14.

Exhibiting: Ideal gas-fired boilers (in operation). Wolff gas-fired steam radiators and Wolff gas-fired pressed steel radiators. Wolffire room heaters, Nos. 4, 8, 18 and 28. Wolff visible toaster.

In Attendance: W. T. Rasch, president, and A. A. Higgins, New England representative.

QUENCHING DIAGRAMS FOR CARBON STEELS IN RELATION TO SOME QUENCHING MEDIA FOR HEAT TREATMENT†

By H. J. FRENCH AND O. Z. KLOPSCH

Prefatory Abstract

This report relates to "quenching diagrams" for carbon steels containing from 0.25 to 1.25 per cent carbon. In these are shown the relations between Rockwell hardness, microstructure, thermal transformations and the cooling velocity determined at 720 degrees Cent. (1328 degrees Fahr.). A discussion is given covering the general relations between the "quenching diagrams" and various quenching media for heat treatment, such as water at different temperatures, oils, sulphuric acid solutions of various concentrations, brines and sodium hydroxide solutions.

INTRODUCTION

DURING the past few years the more or less widely discussed problems associated with "abnormality" (13), (14), (15), (17),* in low-carbon (carburizing) and other steels, and control of dimensional changes in hardening and subsequent permanence in tool, die and gage steels, have served to emphasize the need for more quantitative data concerning quenching media for heat treatment. Examination of published information likewise discloses many apparent discrepancies for even the commonly used quenching solutions.

Accordingly an investigation was started during the latter part of 1923, which had for its object the determination of the

"quenching power" of various solutions and a study of their characteristics in relation to use for hardening steels. The preliminary experiments were patterned after the work of some earlier investigators, in which cooling curves were taken at the center of cylinders of fixed dimensions made of a material having no marked thermal transformations.

Upon examining the results it was found that some of the desired comparisons involved such small differences in the time-temperature curves that it appeared hazardous to accept results without confirmatory tests with steels. It, therefore, seemed logical to determine the effects of the various media directly upon steel samples with which not only cooling times or velocities could be determined, but likewise a study made of the resulting hardness, microstructure and the lowering and suppression of the thermal transformations.

It is the purpose of this report to describe the results obtained in such experiments particularly in relation to "quenching diagrams" for carbon steels, as it is considered that these will form a background and, possibly, also a good basis of comparison for the main portion of the investigation of quenching media. Only a general discussion of the properties of a few commonly used or special media will be included as the main work in this phase of the investigation is now in progress and, it is expected, will be reported at a later date.

Previous Investigations

As this report covers but one phase of the general problem no lengthy review will be given of the many earlier related investigations. References of particular interest in connection with the described tests are given in the appended bibliography and such comparisons with previously published results as appear desirable will be included in the body of the report.

Methods of Test and Equipment Used

The methods of test employed in construction of the "quenching diagrams" were substantially to obtain time-temperature curves on different steels during quenching in various media

under known and reproducible conditions, and, thereafter, to study
the microstructure and hardness of the quenched samples.   In
general wide variations in the character and rates of cooling were
obtained by the use of different quenching solutions (Table II),
and a fixed size and shape of sample.   In some cases, however, in
which intermediate points were desired on the final "quench-
ing diagrams" or very rapid cooling rates sought, the diameter
of the sample was also modified.   To test the accuracy of the re-
sults so obtained, one series of tests was likewise made in which
the sample-size alone was varied and the quenching medium was
kept constant.

Ordinary galvanometers or potentiometers are entirely un-
suited for detecting the thermal transformations and even follow-
ing the time-temperature relations in quenching, on account of the
rapid rates of temperature change encountered.   An Einthoven or
"string galvanometer" was used in spite of the fact that it barely
gave sufficient sensitivity for the purpose in view.   The instru-
ment available was similar to one employed a few years ago
by Pilling and Lynch (10) and the principle of its operation
and application in quenching experiments has already been de-
scribed in detail by these authors and others (2).   It will, there-
fore, only be necessary to point out salient features concerning
the particular instrument used.

The galvanometer consisted of a tungsten wire or "string,"
either 0.0003 or 0.0004 inch in diameter, suspended in a strong
magnetic field.   When such a wire is connected to a source of
electromotive force (emf.), which may be a thermocouple, a de-
flection is obtained which is proportional to the current in the
string circuit; if the resistance of the string circuit and the mag-
netic field remain constant, deflections of the string (if not too
large) are proportional to the emf. and may, of course, be readily
converted into temperature equivalents.   With the equipment used
a change of about 9 millivolts (approximately 950 degrees Cent.
[1742 degrees Fahr.]) with a platinum-platinum rhodium thermo-
couple, was equivalent to about 0.0025 inch maximum deflection
of the string.   Actually the resistance of the string circuit changed
slightly during quenching, owing to the cooling of a considerable
length of heated thermocouple wires, but as will later be shown,
variations introduced in the proportionality between string deflec-
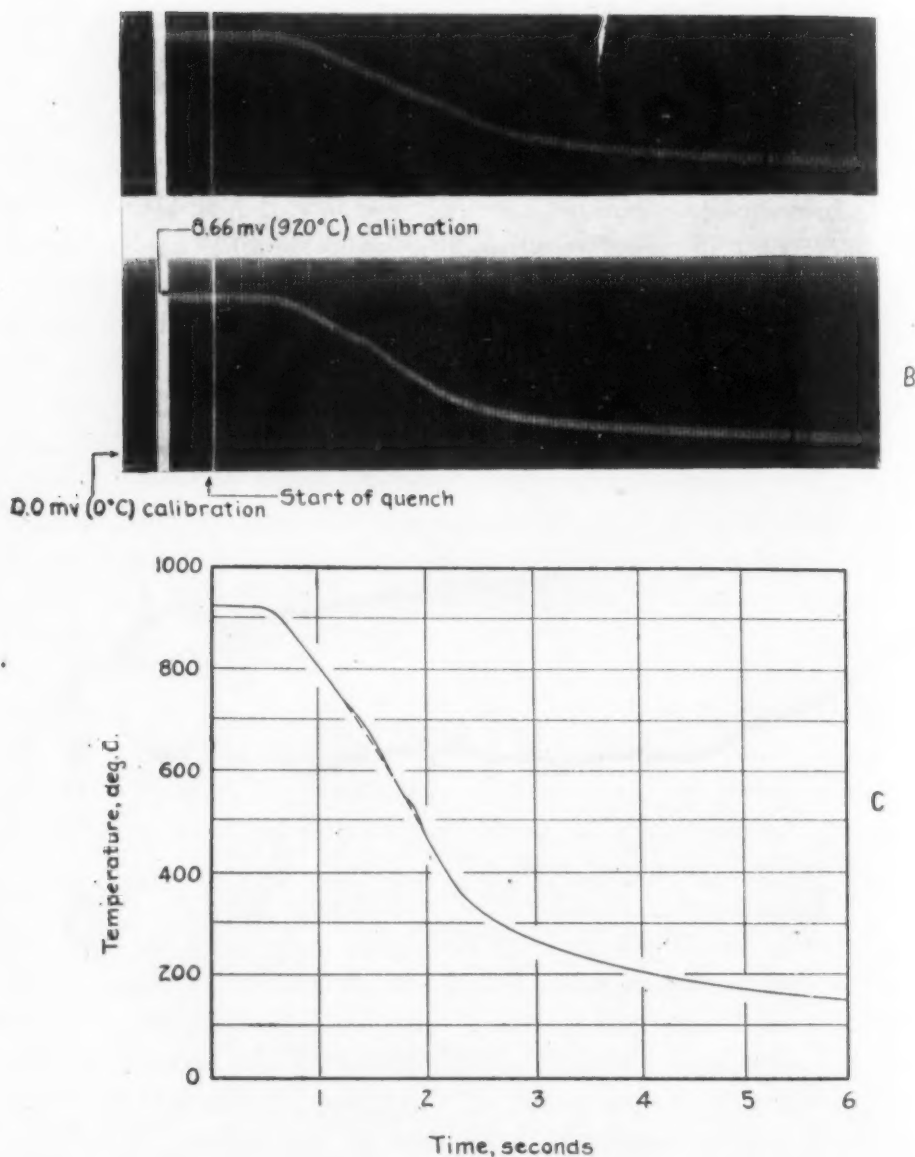tion and emf. by this effect were well within the experimental

Fig. 1 A—Photographic Records and a Re-plotted Time-temperature Cooling Curve Obtained with the "String Galvanometer."

The Wide Band Projected on the Film is the Result of High Magnification of the "String" Shadow ; only the Upper Edge of this is Used in Calibration and Measurement of Temperatures. The Lowest Curve "C" has been Re-plotted to the Same Time Scale but an Expanded Temperature Ordinate in Accordance with the Method Used in a Majority of the Experiments.   The Results were Obtained at the Center of ½-inch Diameter Cylinders Prepared from Steels Containing 0.20 to 0.25 Per Cent Carbon. "B" and "C" were Quenched from 920 Degrees Cent. ; into a Motionless 5 Per Cent Sodium Hydroxide Solution at 21 Degrees Cent. ; "A" was Quenched from 950 Degrees Cent. into the same Solution Flowing at 1 foot per second.

Reproduction of Photographic Records are ⅓ to ½ Original Size and do not Show the Heat Effects as Clearly as do the Original Records.

error and, therefore, could be neglected.   The thermocouples used had wires 0.0077 inch (0.2 mm.) in diameter.

By the use of an arc lamp and suitable optical equipment the

shadow of the string was projected, at about 500 magnification, upon a moving photographic film or paper and a continuous record of temperature variations so obtained. Time intervals were recorded by interrupting the beam of light by means of a slotted
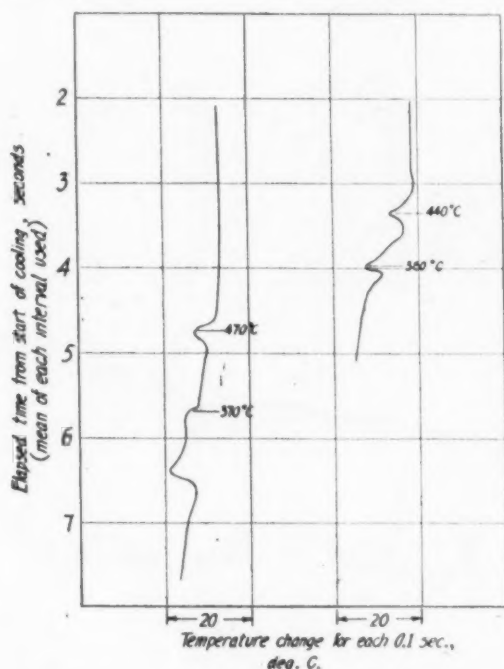

Fig. 1 B—Partially Re-plotted Cooling Curves Showing the Temperature Drop for Equal Time Intervals.
This Method of Re-plotting was Used when the Heat Effects of Ar′ or Ar″ were very Small. The Two Curves Reproduced Show a "Lowered" Ar′ in the Sensitive Zone on the Quenching Diagrams just Below the Critical Cooling Rate. The Curve at the Left was Obtained at the Center of a ½-inch Diameter Cylinder of 0.95 Per Cent Carbon Steel Quenched from 875 Degrees Cent. into Still Water at 40 Degrees Cent.; that at the right is for a Cylinder $\frac{7}{16}$ inch Diameter of 0.75 Per Cent Carbon Steel Quenched from 830 Degrees Cent. into Still Water at 30 Degrees Cent.

disk rotated at constant speed through the use of a synchronous motor and tuning fork. Typical curves obtained with the described apparatus are reproduced in Fig. 1A.

A cylinder was selected as the "standard" form of specimen and in most cases had a diameter of ½ inch and a length of 2 inches. All temperature measurements and the principal microscopic examinations and hardness tests were made at the center of the cylinders. Details of the attachments used to hold the thermocouple in place are shown in Fig. 2, while the method of quenching samples is shown diagramatically in Fig. 3.

The specimen (S) (Fig. 3) with thermocouple (T) in place

and mounted on a carriage (C), which likewise carried an ice-box for constant cold-junction temperatures of the thermocouple, was lowered into the heating unit (H). After the desired center temperature was reached the sample was held ten minutes before quenching and then dropped by means of the lowering cord (L)
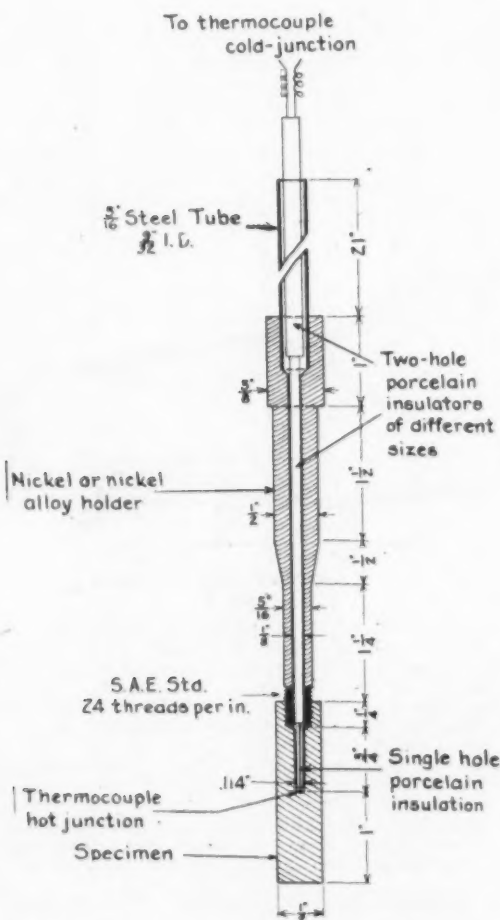

Fig. 2—Method of Mounting Thermocouple in Specimen.

into the quenching solution (Q). The most desirable method of quenching is one which is entirely automatic but it was not practicable at the time these tests were made to install such equipment and, furthermore, the described method was found in repeated experiments to give consistent results.

Control of the rate of motion of the sample in the solution or, what is the same, the rate of motion of the liquid about the sample was had by mounting the quenching tank on a disk (D)

which could be rotated at constant speed by motor (M) and like-
wise mounting these upon a movable platform (P). Different
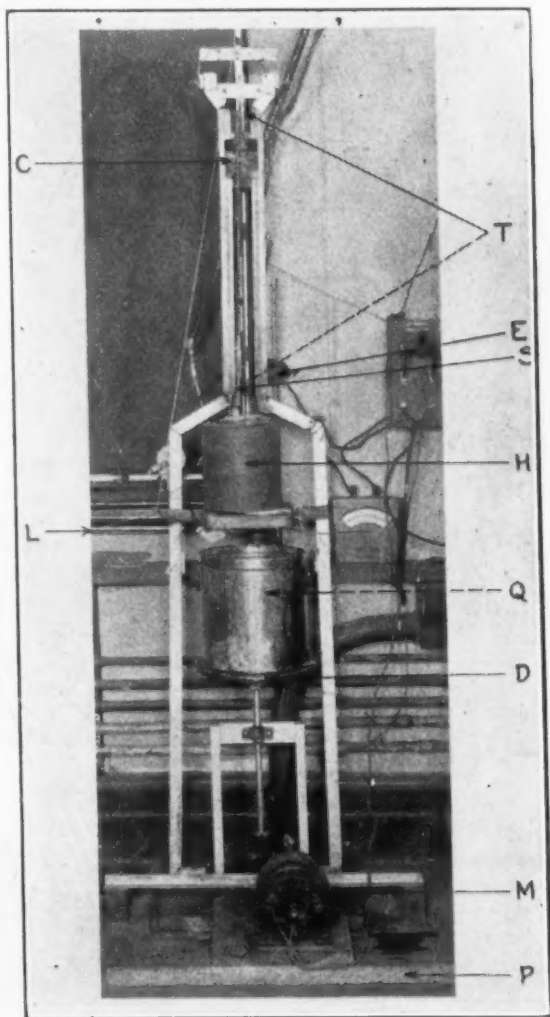rates of motion were obtained by varying the distance of the

Fig. 3—Quenching Equipment Used.

sample from the axis of rotation of the cylindrical quenching
tank. In the case of "still quenching" the tank was not moved.

The start of the quenching was considered to be the time at
which the specimen was half immersed in the quenching bath
and a record of this was made on the film by allowing carriage
(C) to break the circuit (E) of an electromagnet, thus releasing
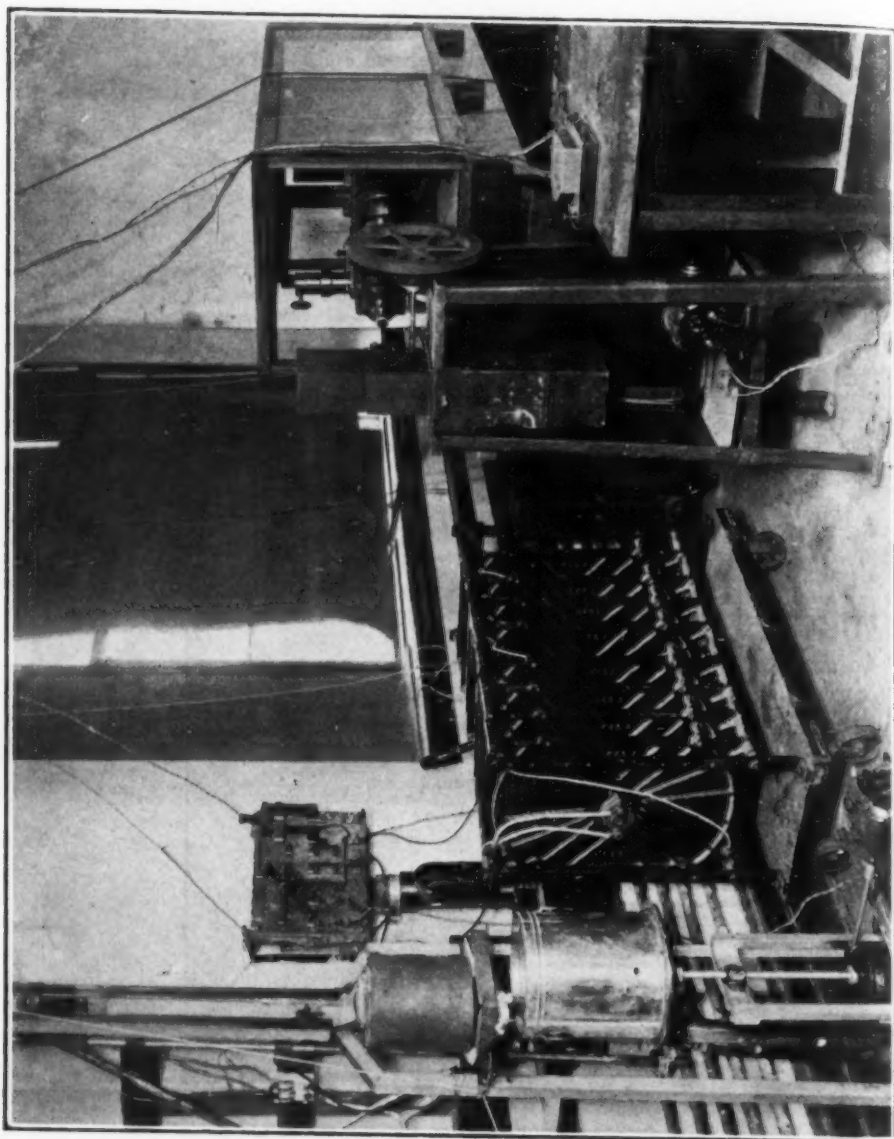an arm so placed that in falling it momentarily cut out the beam

Fig. 4.—Completely Assembled Apparatus Used for Obtaining "Quenching Curves."

of light used to project the string image into the camera. (Refer to Fig. 1A.) A photograph of the completely assembled apparatus is reproduced in Fig. 4.

To obtain consistently accurate results from the described apparatus and procedure, a number of precautions must at all times be observed, of which the following appear most important:

(1) All test samples should preferably be finish machined or ground in the same manner, in order not to change

to any marked degree the character of the surface in contact with the quenching solution and through which the heat is conducted away from the sample.

(2) The smallest practicable thermocouple "bead" should be used and at the same time the largest possible surface contact maintained between it and the sample. Accordingly, after welding the thermocouple wires the "bead" was cut in half so as to have a flat surface in contact with the specimen instead of point contact, such as would be given by a spherical tip.

(3) A clean metal surface must be exposed to the thermocouple. If, as is ordinarily the case, a coolant is used in drilling the hole to the center of the specimen, all oil, small particles of metal and other foreign substances should be flushed out with gasolene or other suitable cleansers.

(4) The thermocouple must be so mounted that a fairly uniform and good contact pressure is maintained with the specimen during heating and cooling. Various methods were tried with the result that the arrangement shown in Fig. 2, sometimes with an added set-screw not shown in the diagram, was selected. In this arrangement good contact pressure depends largely upon the proper proportions between the insulation and container tubes and careful insertion of the thermocouple into the specimen; while not an ideal arrangement, it was found to be satisfactory for the work in view.

(5) None of the quenching solution can be permitted to come in contact with the thermocouple during quenching. Thus the joints between the specimen and tubes through which the thermocouple passes (Fig. 2) must be leak-proof and so constructed that they remain intact during heating and rapid cooling.

(6) An accurate calibration of the thermocouple is essential. The heated ends of the platinum-platinum rhodium wires become contaminated quite rapidly under the described conditions of test, so that it was the practice to cut off approximately half an inch of both wires after each experiment and then re-weld.

In addition to the above it is necessary to have all contacts in the string-thermocouple circuit tight and, to avoid outside inter- ferences the leads should preferably be lead covered.

Calibration of the complete set-up was made before each quenching and was carried out substantially as follows: When the desired center temperature had been reached in the specimen (and maintained for 10 minutes), as indicated by a potentiometer-
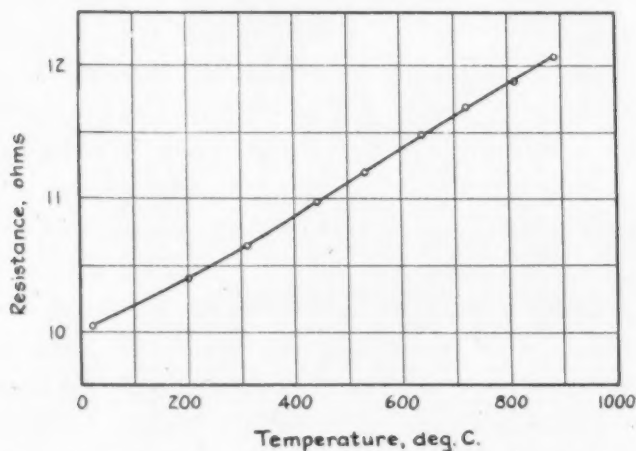

Fig. 5—Change in Resistance of Thermocouple (with Copper Leads) during a Heating or Cooling Cycle with the Equipment Described.
These Values were Used in Determining Errors in Calibration of the Apparatus which would Result from Neglect of the Change in Resistance of the Thermocouple.

indicator, the thermocouple was connected to the string and rec- ords of its deflection and "zero position" immediately made on the recording film or paper (Refer to Fig. 1A). The specimen was then quenched and subsequently another record made of the base position of the string to avoid errors from possible movement in the camera equipment.

Since the string positions are now known accurately at the chosen maximum temperature of heating and at 0 degrees Cent. (32 degrees Fahr.), and since string deflections are proportional to emf., pro- viding the resistance of the string circuit remains constant, the described procedure gives a temperature calibration for the appa- ratus. As already indicated, the resistance of the string circuit changes to some extent during quenching on account of the change in resistance of the thermocouple, due to cooling of a considerable

length of the heated wires. However, this effect is relatively small, as shown by data given in Figs. 5 and 6, and may be neglected in these experiments because the variations are well within the limits of experimental error.

Calibration of the time marker was likewise checked before

Temperature, deg C.
as given by proportionality between string
deflections and e.m.f.

For quenching temperature of 920°C

For quenching temperature of 875°C
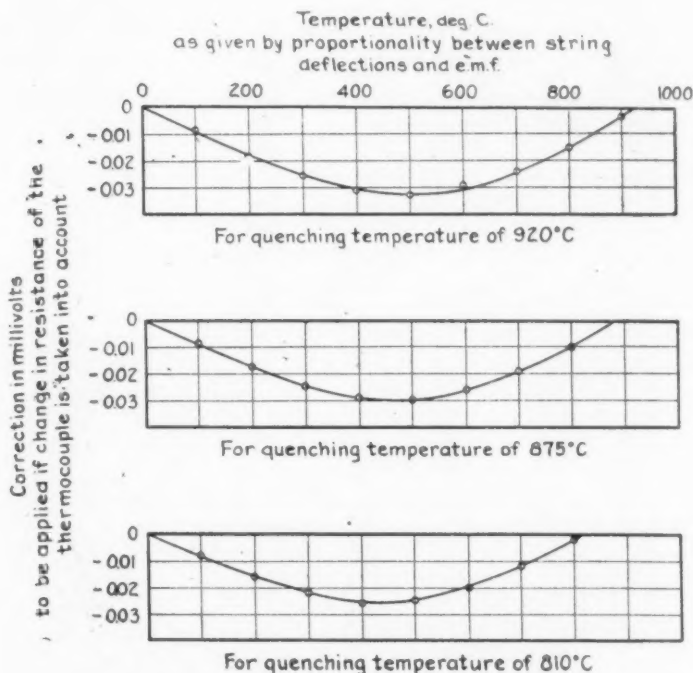
For quenching temperature of 810°C

Fig. 6—Corrections to be applied when Using Various Quenching Temperatures to the Proportionality between String Deflections and emf. as a Result of Resistance Changes in the Thermocouple Circuit During Quenching.
Note that the Maximum Error Introduced by Neglect of these Changes is about 0.03 mv or 3 Degrees Cent. with the Platinum Thermocouples Used. Values were Calculated from Data given in Fig. 5 and the Resistance of the "String" which was Equal to 105.4 ohms.

and after each quenching experiment by actual measurement of the speed of the driving rolls for the recording film in the camera.

EXPERIMENTAL RESULTS

Compositions and Character of Steels Used

It is now widely recognized that considerable variation may be observed in both performance and heat treatment characteristics between different heats of steel of identical composition insofar as the ordinary chemical determinations are concerned. The comparatively recent work of McQuaid and Ehn (13), (14), (15), shows that such variations may affect the ease of hardening to an

appreciable degree, or to state this somewhat differently, that various heats of steel of like composition (as now determined) may require very different quenching methods for martensitization or "complete hardening."

As the tests carried out in this investigation include determination of the cooling rates required for martensitization (referred to as "critical cooling rates") for steels of different carbon contents, it was considered necessary first to obtain some tangible indication of characteristics peculiar to the individual heats used. While our knowledge of the microstructural features of the steels most easily hardened ("normal steels"), and those requiring more drastic quenching ("abnormal steels") is somewhat limited, it was considered desirable to have on record for future reference results obtained in the McQuaid-Ehn carburizing test. Therefore, in addition to the chemical compositions of the six steels given in Table I, the results of the "carburizing test" are shown in Figs. 7 and 8.[1]

Table I
Chemical Compositions of the Steels Studied

| Steel | Chemical Composition—Per Cent | | | | |
	C	Mn	P	S	Si
C31	0.25	0.51	0.011	0.036	0.01
C33	0.43	0.60	0.018	0.023	0.11
C29	0.75	0.29	0.011	0.023	0.11
A316	0.89	0.33	0.014	0.035	0.18
C27A	0.96	0.21	0.019	0.018	0.21
C28	1.27	0.21	0.013	0.021	0.17

In general the characteristics revealed are those of "normal steels." The heat containing 0.75 per cent carbon shows a slight decrease in grain size in the carburized zone, typical of abnormal steels, but no cementite coagulation; it is, therefore, questionable whether this steel can be classed as other than normal. Some graphitization is shown in the steel containing 1.27 per cent carbon in condition as received, but no noticeable variations in hardness or quenching characteristics were observed.

Quenching Diagrams for Steels of Various Carbon Contents

Quenching diagrams for steels varying from 0.25 to about 1.25 per cent carbon are given in Figs. 9 to 15 inclusive. In these are

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[1] The carburizing tests and interpretation of results for the various steels used were made by S. Epstein who for some time has been studying the characteristics developed in steels of varying degrees of "abnormality."
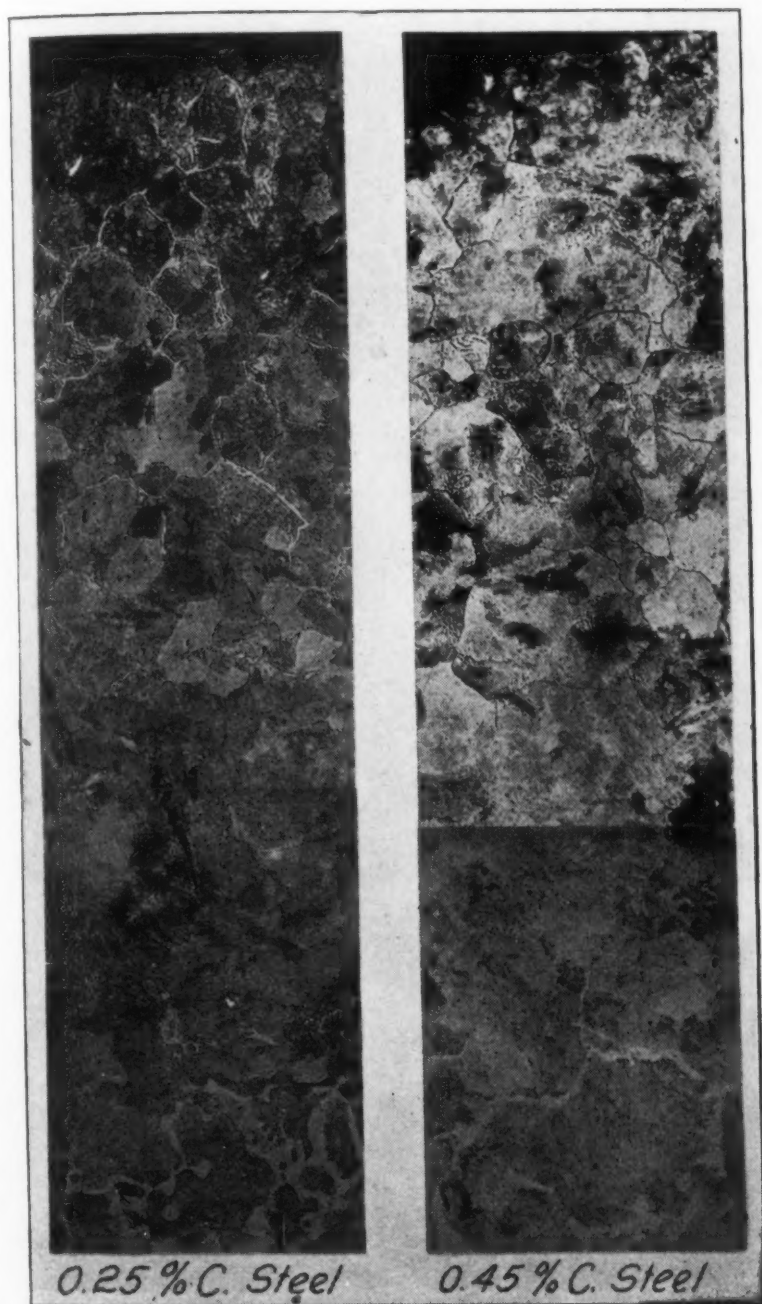
Fig. 7—Microstructures Produced in the 0.25 and 0.45 Per Cent
Carbon Steels in the McQuaid-Ehn Test.   Etched with 2 Per Cent Nitric
Acid in Alcohol. x 100.

shown the relations between cooling velocity, measured at 720 de-
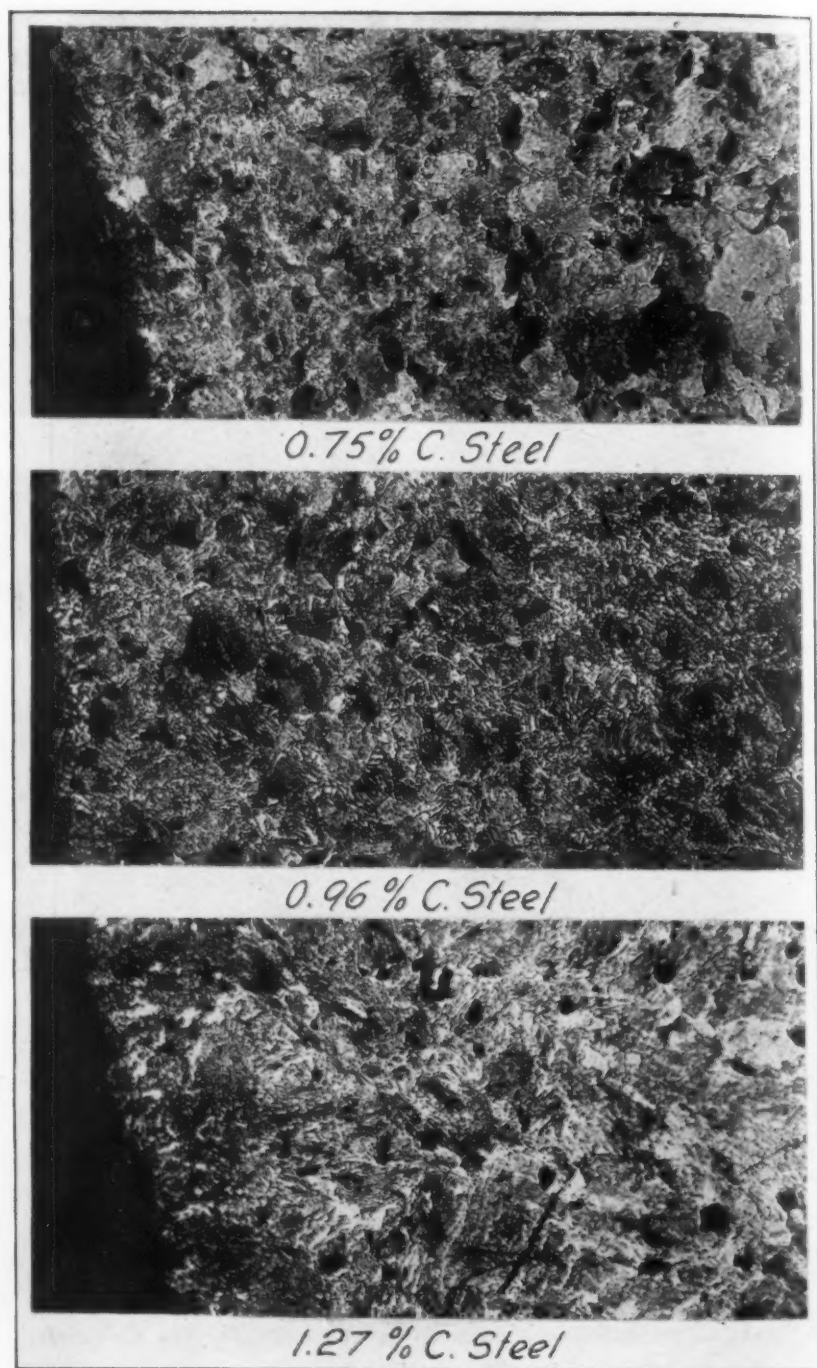grees Cent. (1328 degrees Fahr.) and the microstructure, thermal

Fig. 8—Microstructures Produced in the 0.75, 0.96 and 1.27 Per Cent Carbon Steels in the McQuaid-Ehn Test. Etched with 2 Per Cent Nitric Acid in Alcohol. x 100.

transformations[2] and Rockwell hardness. Before discussing the
nature and application of these diagrams it should be emphasized
that reference of the several properties mentioned to a single
cooling velocity will not take into account all factors which should
be considered but offers a simple and ready method of comparison
at the present stage of the investigation. It will here be used
since several other more complicated modes of comparison tried,
gave no more information of general interest or application. In
all cases the temperatures of occurrence of transformations were
taken as the detectable beginning of the heat effects on cooling.

Examination of Figs. 9 to 15 inclusive shows that the nature
of the quenching diagrams is the same for all the steels and it
will, therefore, suffice to briefly discuss their general form and
subsequently to compare such features as appear of importance in
relation to steels of varying carbon contents.

It will be noted that as the cooling rates increase the thermal
transformation Ar_1 is at first gradually and slowly lowered and
subsequently split into two heat effects at widely different temper-
atures. The upper one, commonly called Ar' and coincident with
the formation of troostite, occurs at first at relatively high tem-
peratures, while the lower point Ar'' at which martensite is formed
is observed between 375 and 550 degrees Cent. (707 and 1022
degrees Fahr.) depending largely upon the carbon and manga-
nese contents of the steel. With further increase in cooling speed
the lower point increases in intensity but remains at approximate-
ly the same temperature, while the upper decreases and is at the
same time lowered until its temperature of occurrence approaches
that of Ar''. With sufficiently rapid cooling, only the low point
is observed and a martensitic or "completely hardened" steel is
obtained. The cooling velocity which first results in a marten-
sitic steel free from troostite is called the "critical cooling rate."

The nature of these effects has long been known but the dia-
grams differ in at least one important detail from the usual con-
ceptions covering carbon steels, and as far as the authors are
aware represent a more complete determination than has so far
been published. At least in some quarters it has been considered

[2]720 Degrees Cent. (1328 Degrees Fahr.) was chosen as a reference point because it is
slightly above Ar_1 in carbon steels where the cooling velocities largely determine the initial
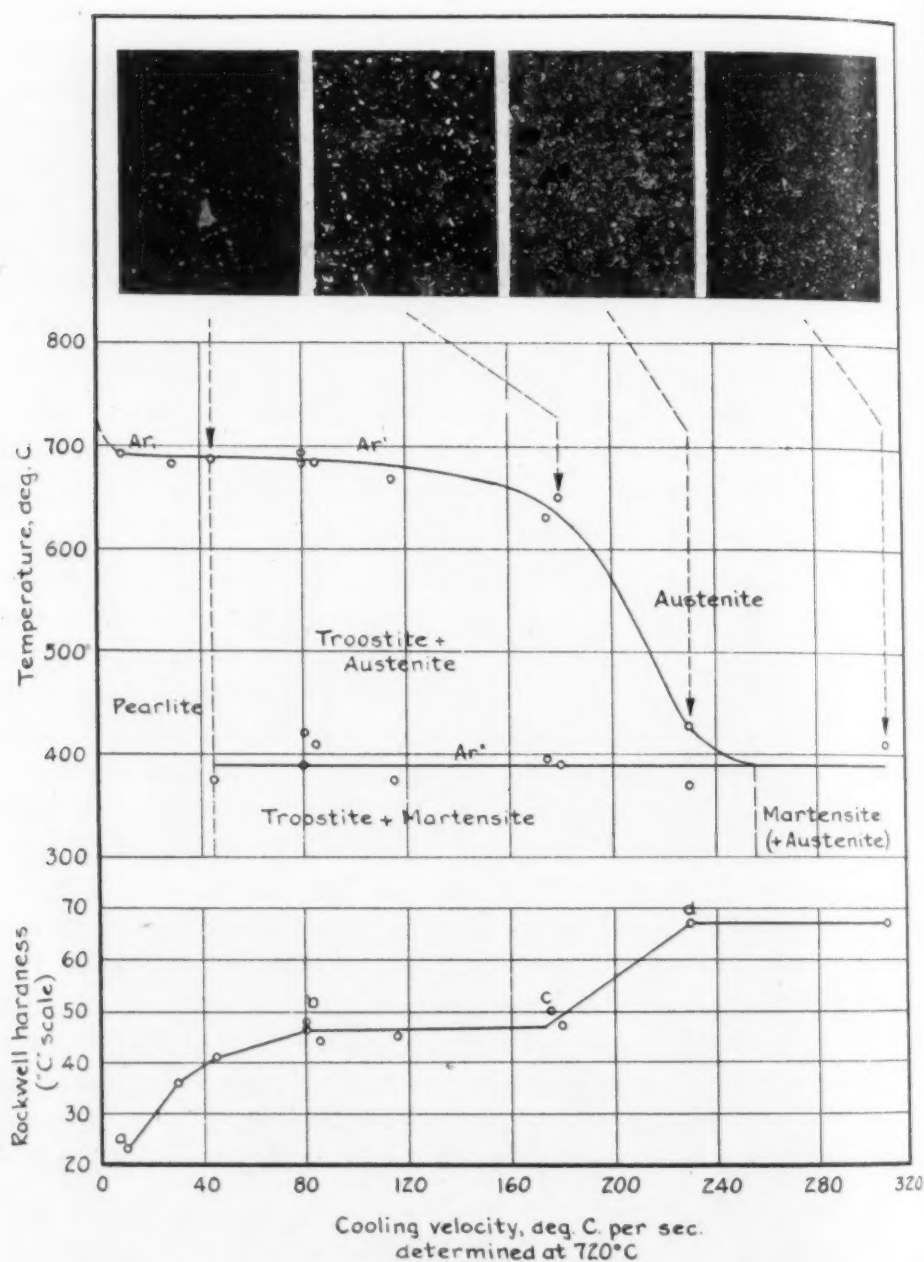lowering of this transformation.

Fig. 9—"Quenching Diagram" for 1.27 Per Cent Carbon Steel Quenched from 810 Degrees Cent. Microstructures given at 500 Magnification for Sample Etched with 2 Per Cent Nitric Acid in Alcohol.

(A). To Determine Whether the Dark Areas Shown in the Two Photomicrographs at the Extreme Right were Troostite or Graphite Examination of Unetched Sections was also Made.

(B). The Retention of Austenite is Indicated in this and Subsequent Diagrams (Figs. 9 to 14 inclusive) only for Rates Higher than the Critical. The amount Retained Increases with the Velocity of Cooling, and it should therefore be Recognized that Some may be Present in Steels Cooled Somewhat More Slowly.
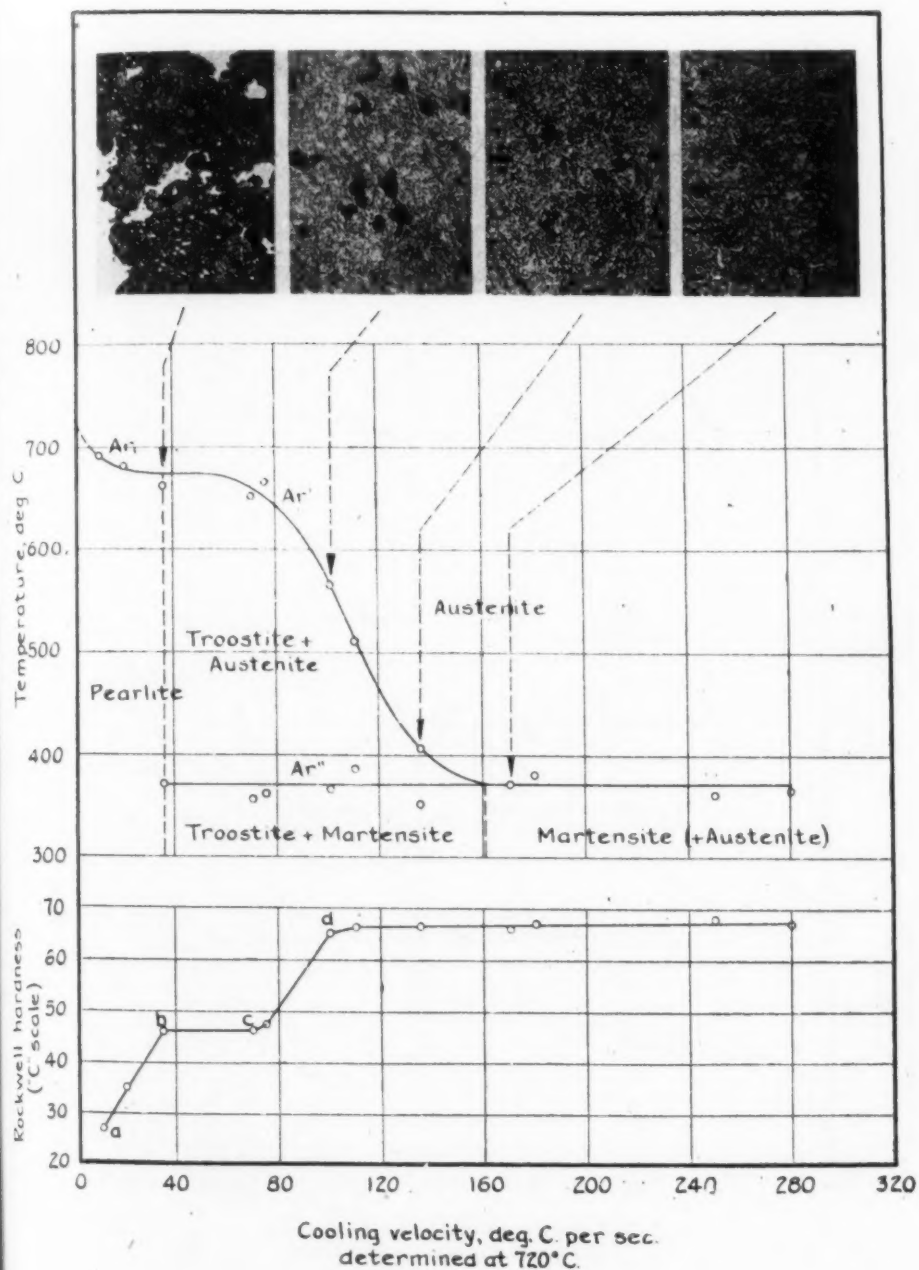
Fig. 10—"Quenching Diagram" for 0.95 Per Cent Carbon Steel Quenched from 810 Degrees Cent. Microstructures given at 500 Magnification for Samples Etched with 2 Per Cent Nitric Acid in Alcohol. Refer also to Note (B), Fig. 9.

that a sharp discontinuity existed at the critical cooling rate and that Ar′ was not lowered very materially before it disappeared
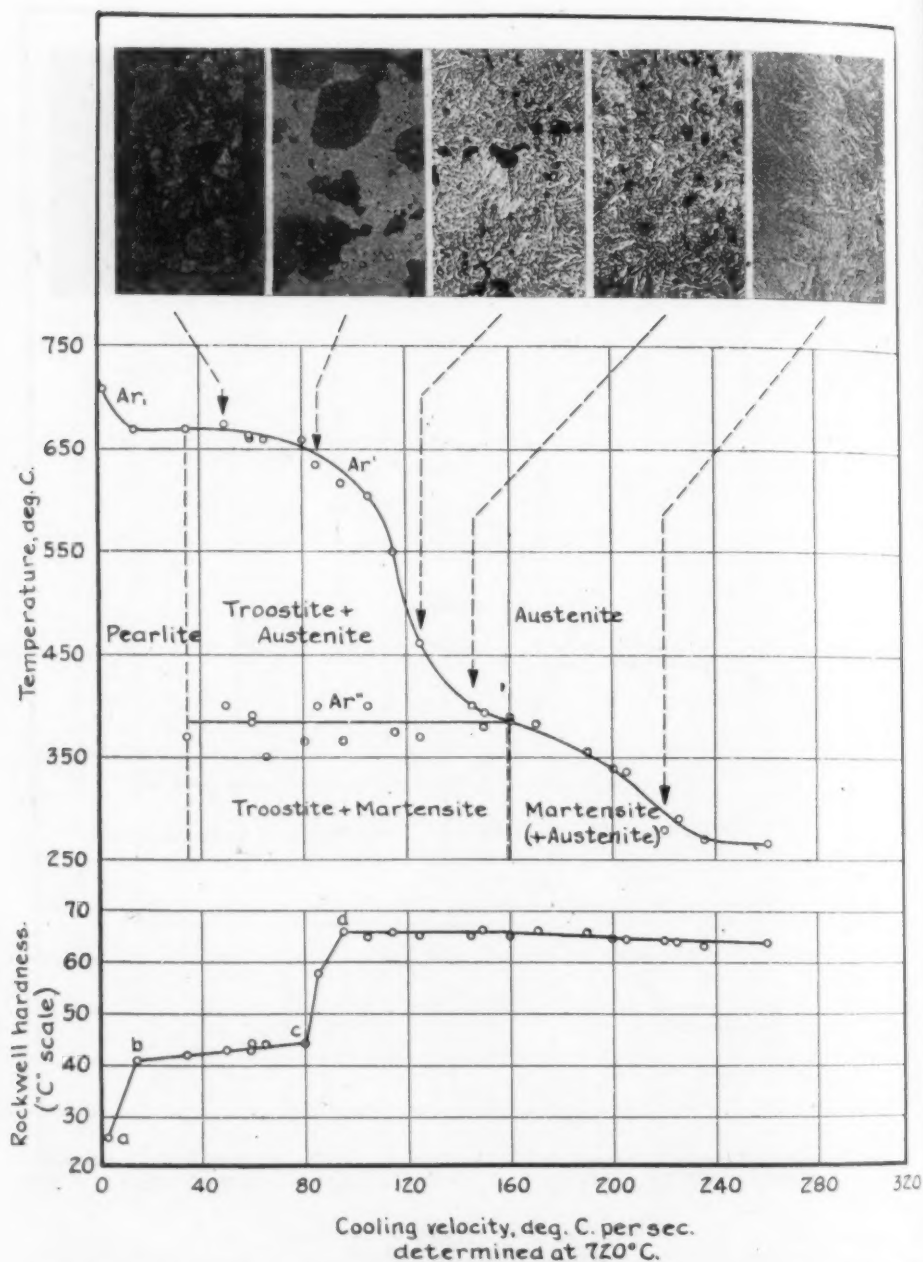
0.96% C Steel

Fig. 11—"Quenching Diagram for 0.95 Per Cent Carbon Steel Quenched from 875 Degrees Cent. Microstructures given at 500 Magnification for Samples Etched with 2 Per Cent Nitric Acid in Alcohol. Refer also to Note (B), Fig. 9.

abruptly in favor of Ar". That such an effect, already reported for air hardening steels, is not observed in commercial carbon steels when quenching from within and slightly above the ordinary
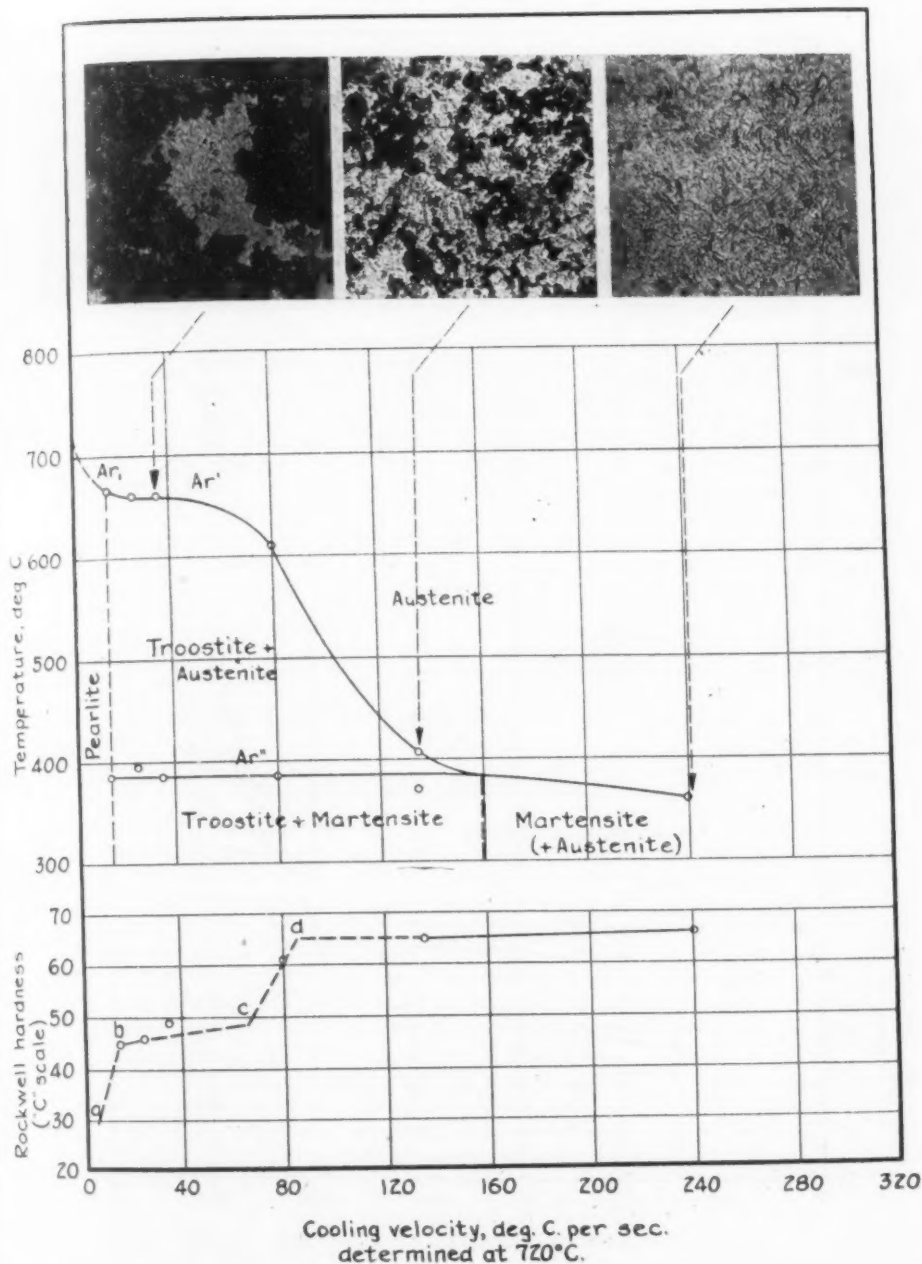
Fig. 12—"Quenching Diagram" for 0.89 Per Cent Carbon Steel Quenched from 875 Degrees Cent. This Diagram, Unlike those in Figs. 9 to 11 and 13 and 14, was Obtained by Varying the Sample Diameter from ⅜ to 2 inch, but with a Constant Ratio of Length to Diameter of 3. Its Sole Purpose is to Check Results Obtained by Using Different Quenching Media. Microstructures given at 500 Magnification for Samples Etched with 2 Per Cent Nitric Acid in Alcohol. Refer also to Note (B), Fig. 9.

hardening temperature range, is quite clearly shown in Figs. 9 to 15 inclusive.

0.75 % C Steel

Fig. 13—"Quenching Diagram" for 0.75 Per Cent Carbon Steel Quenched from 830 Degrees Cent. Microstructures given at 500 Magnification for Samples Etched with 2 Per Cent Nitric Acid in Alcohol. Refer also to Note (B), Fig. 9.

Unfortunately it was not practicable with the chosen methods of test to locate as accurately as desired, the cooling rates at which Ar_1 first splits on account of the small heat effect of the lower
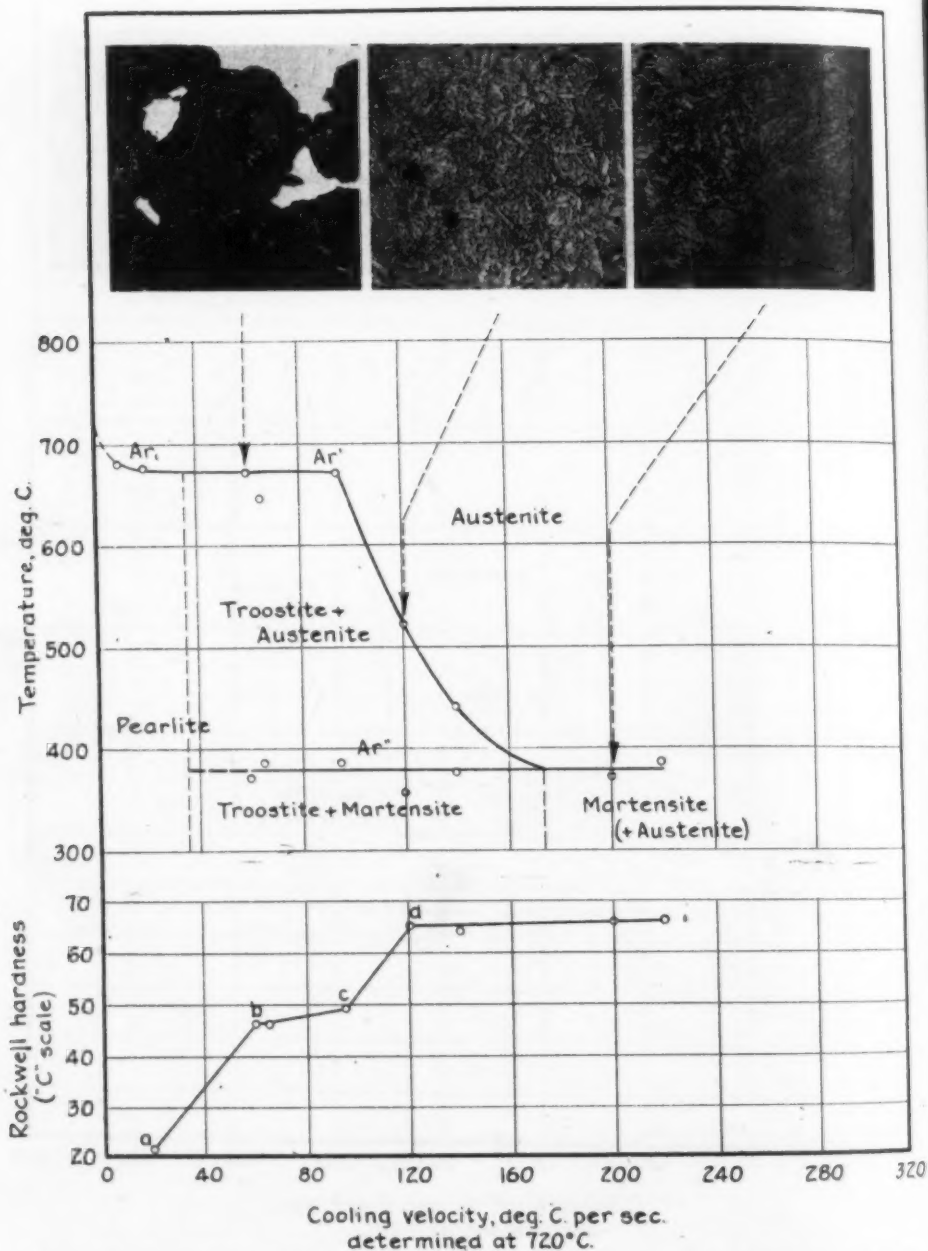
0.45 % C Steel

Fig. 14—"Quenching Diagram" for 0.45 Per Cent Carbon Steel Quenched from 875 Degrees Cent. Microstructures given at 500 Magnification for Samples Etched with 2 Per Cent Nitric Acid in Alcohol. Refer also to Note (B), Fig. 9.

transformation, Ar″, and the inability to detect extremely small proportions of martensite by either microscopic examination or Rockwell hardness tests.   Further complications arise from the fact that a marked retardation in cooling velocity is observed at
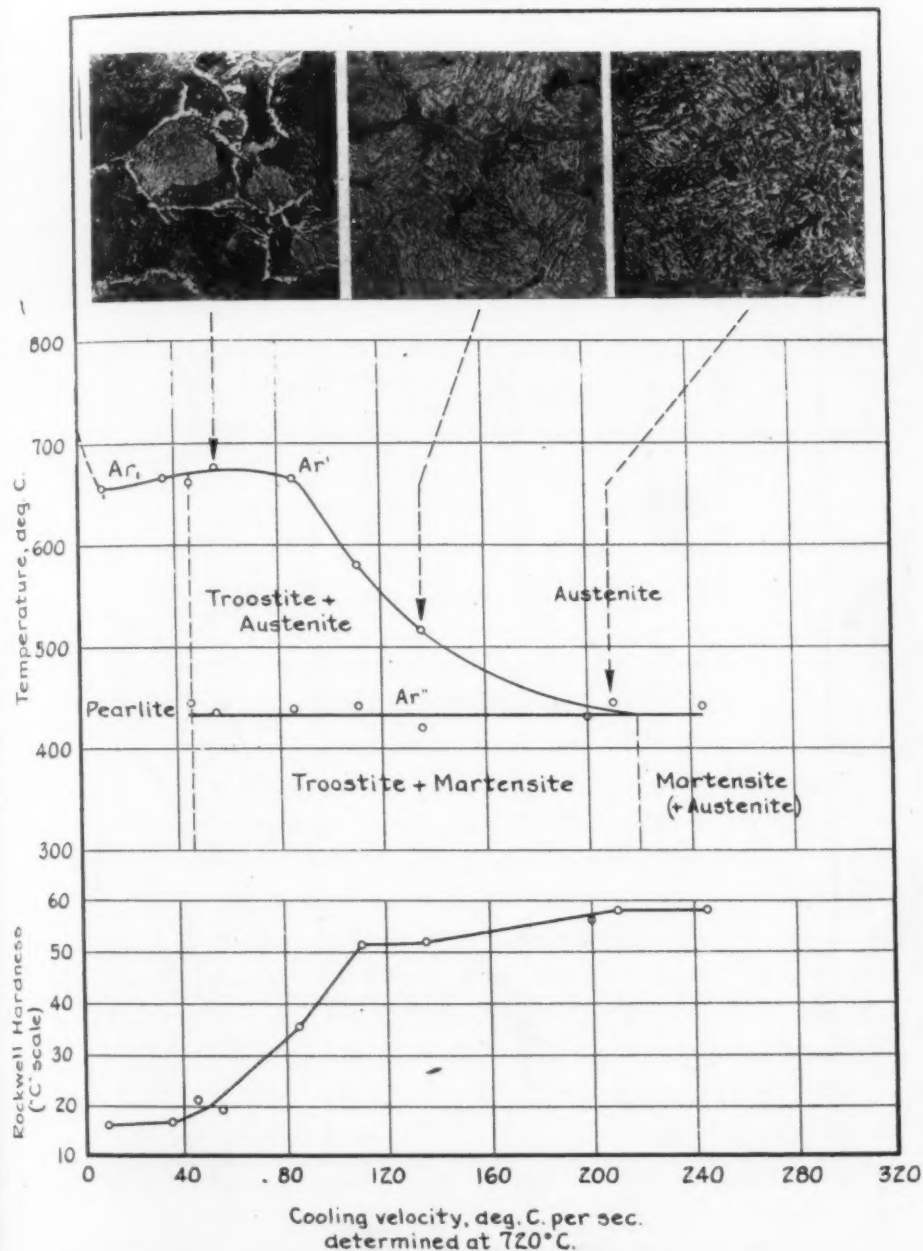
0.25% C Steel
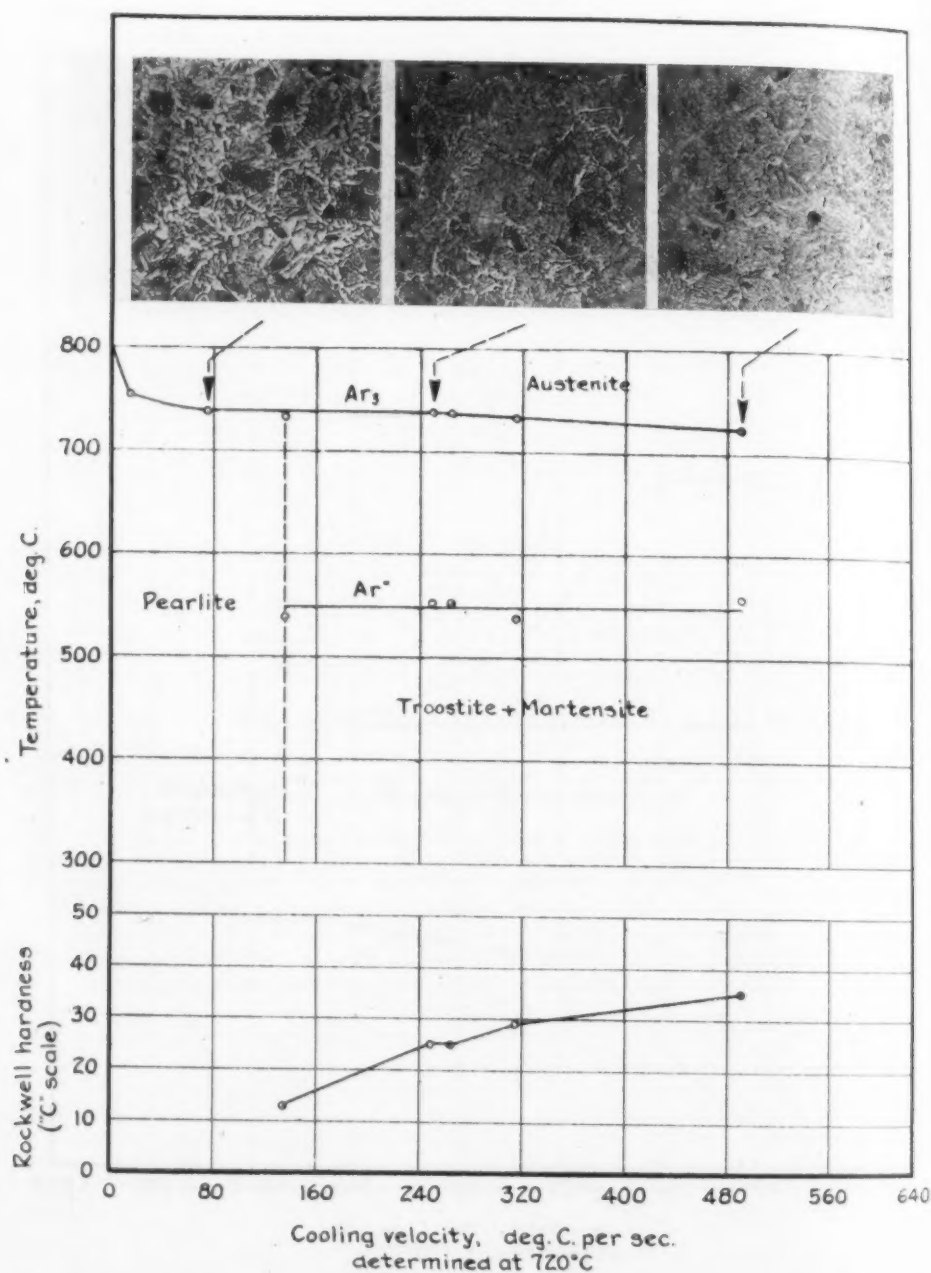
Fig. 15—Part of the "Quenching Diagram" for 0.25 Per Cent Carbon Steel Quenched from 920 Degrees Cent. Microstructures given at 500 Magnification for Samples Etched with 2 Per Cent Nitric Acid in Alcohol. Note that this Diagram is Incomplete and that the Upper Line is Ar₃. A heat effect from Ar₁ or Ar′ could not be Detected With the Methods Used.

temperatures just below Ar″, when using ordinary quenching oils for studying this portion of the quenching diagrams, so that any martensite formed is undoubtedly tempered in part while the

steel cools slowly to room temperatures. For this reason water at various temperatures was largely used.

The customary terminology has been used in discussing the quenching diagrams merely as a matter of convenience for demonstrating the effects of various coolants on some of the properties of carbon steels. It is not to be inferred that the authors agree to the conception of a true splitting of Ar_1 as the designated positions of Ar' and Ar'' may merely represent the maximum speed of reactions in a transformation range which has widened materially. However, such theoretical considerations are removed from the purpose of either the report or the described tests.

Attention should also be called to the fact that the "scatter" of points representing Ar' is about 10 degrees Cent. from the mean curve selected; that for Ar'' is within about 25 degrees Cent., except in the case of the 0.95 per cent carbon steel quenched from 875 degrees Cent. (1607 degrees Fahr.) when somewhat wider variations are observed.

The results of both microscopic examination and Rockwell hardness tests on quenched samples confirm the changes indicated by the thermal transformations and no extended discussion of these data will be necessary. In the steels containing 0.75 per cent or more of carbon the hardness increases with the cooling rate until a fairly large amount of troostite is present (region ab). It then remains practically constant over a well defined range (bc) until the cooling has been sufficiently rapid to make martensite the predominating factor when it again increases (region cd). Above the critical cooling rate and within the limits investigated, the hardness remains very nearly constant, though there is undoubtedly more and more austenite retained as cooling rates increase. Hardness curves, unlike those for the thermal transformations, have been plotted with sharp breaks through points of observations; somewhat more gradual changes would undoubtedly be shown with the acquisition of intermediate points on these curves.

Particular attention should be called to the fact that in the steels containing from 0.75 to 1.25 per cent carbon practically identical hardness values are obtained whether small but appreciable proportions of troostite are present or a completely martensitic product (not containing too much austenite) is produced

by quenching.[3] Experience has shown material differences in performance between these structural types in cases where abrasive resistance and toughness or strength are paramount, such as case hardened gears in automotive construction.[4] Therefore, at least in some important cases, indentation hardness tests of commercial accuracy, both above and slightly below the critical cooling rate, will not insure correct heat treatment nor guarantee performance depending upon such heat treatment.

A number of important features are revealed in comparison
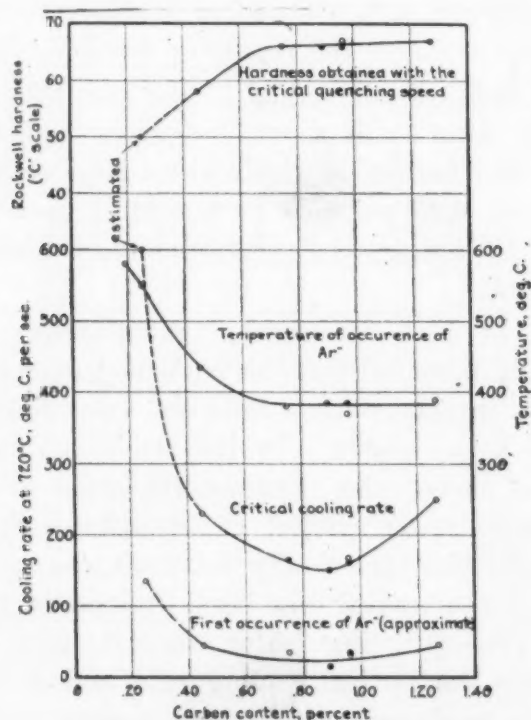
Fig. 16—Effect of Carbon Content on the Critical Cooling Rate and Some Other Features of the Quenching Diagrams for Carbon Steels when Quenched Under Definite Conditions. In all Except Two Cases Represented by Solid Black Circles in which the Samples were Cooled from 875 Degrees Cent., Quenching was Carried out from about 75 Degrees Cent. Above Ac_3 for Hypoeutectoid Steels and Ac_1 for Hypereutectoid Steels.

of the quenching diagrams for steels of different carbon contents and some of these are shown graphically in Fig. 16. Probably

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[3]The use of such terms as "completely martensitic," "fully hardened," "completely hardened," or "complete martensitization," refers to steel which is mainly martensitic, but free from troostite. It should, however, be recognized that varying proportions of austenite are probably retained by the rapid cooling.

[4]Private communication.

of greatest interest is the quenching speed which first results in a fully hardened martensitic steel free from troostite. Steel in the neighborhood of the eutectoid composition (0.85 per cent carbon) has a critical cooling rate of 160 degrees Cent. (320 degrees Fahr.) per second; increase or decrease in carbon raises this materially so that in steels containing either 0.40 or 1.25 per cent carbon the critical rate is about 250 degrees Cent. (482 degrees Fahr.) per second. Thus steels in the neighborhood of the eutectoid composition are more readily hardened than either higher or lower carbon steels, for they will become martensitic with much slower cooling, under otherwise comparable conditions of treatment.

The relation of carbon content to the temperature of occurrence of Ar″ is likewise shown in Fig. 16. This transformation at which martensite is formed during quenching is lowered with increase in carbon to about 0.60 to 0.70 per cent; it remains at about 375 degrees Cent. (707 degrees Fahr.) for steels containing between about 0.70 to 1.25 per cent carbon. The same type of curve is obtained for the relation between carbon content and the cooling rate at which Ar″ is first observed, though these latter results are approximate for reasons already described.

The hardness obtained with the critical cooling rate, which for steels above about 0.70 per cent carbon is practically the same as the maximum hardness obtainable with a given quenching temperature, increases very rapidly with carbon content up to about 0.70 per cent but thereafter remains constant between 66 and 68 on the Rockwell "C" scale.

The results discussed in preceding paragraphs were obtained with two exceptions (Figs. 11 and 12) by quenching from a temperature about 75 degrees Cent. above Ac_3 for hypoeutectoid steels and Ac_1 for hypereutectoid steels. This is generally higher than the hardening temperatures used commercially for small sections especially in the case of the high carbon steels and was selected to emphasize the changes to be studied. A complete series of experiments was also carried out with the 0.95 per cent carbon steel quenched from about 140 degrees Cent. above Ac_1. As shown in comparison of Figs. 10 and 11 the only marked variation in the form of the quenching diagrams is in the slope of the line representing Ar″ at cooling speeds greater than the critical. With the

higher initial temperature (875 degrees Cent.) this slopes sharply downward so that when cooling at 250 degrees Cent. per second at 720 degrees Cent. martensite is formed at about 260 degrees Cent. instead of 375 degrees Cent. However, there is no observable change in the critical cooling velocity with this increase in initial temperature.

In most cases the heat effects at points called Ar' and Ar" are of sufficient magnitude to be readily detected in the time-temperature cooling curves (Fig. 1A) but in the neighborhood of the critical cooling rate where a marked lowering of Ar' is observed, they are generally very small. This applies particularly to Ar', which can only be detected with certainty by such methods of re-plotting, as are shown in Fig. 1B, in which is recorded the temperature drop for equal time intervals approximating 0.1 or 0.2 second. Neglect by previous investigators of the lowering of Ar' in the neighborhood of the critical cooling rate is undoubtedly due in large part to the fact that the small heat evolution which is only recorded in extremely sensitive equipment is not readily detected in time temperature curves.

Relation of Some Quenching Media to Quenching Diagrams and Some Properties of Carbon Steels

So far discussion has been restricted to the relations between cooling velocities and the properties of carbon steels, particularly hardness, microstructure and thermal transformations. This will now be supplemented by brief consideration of the relations between cooling velocities and some common media so as to obtain a conception of the effect of various quenching solutions upon some of the properties of carbon steels. As already indicated, an extended discussion of this subject is not within the scope of this report, so that only a few qualitative comparisons will be made for a fixed size and shape of material, namely, $\frac{1}{2}$ inch round sections.

In Fig. 17 are shown the thermal transformations and structures produced in 0.45, 0.75, 0.95 and 1.25 per cent carbon steels with varying rates of cooling. Data have been omitted for the 0.25 per cent carbon steel, as this does not respond to heat treatment to the same degree as the higher carbon alloys and the
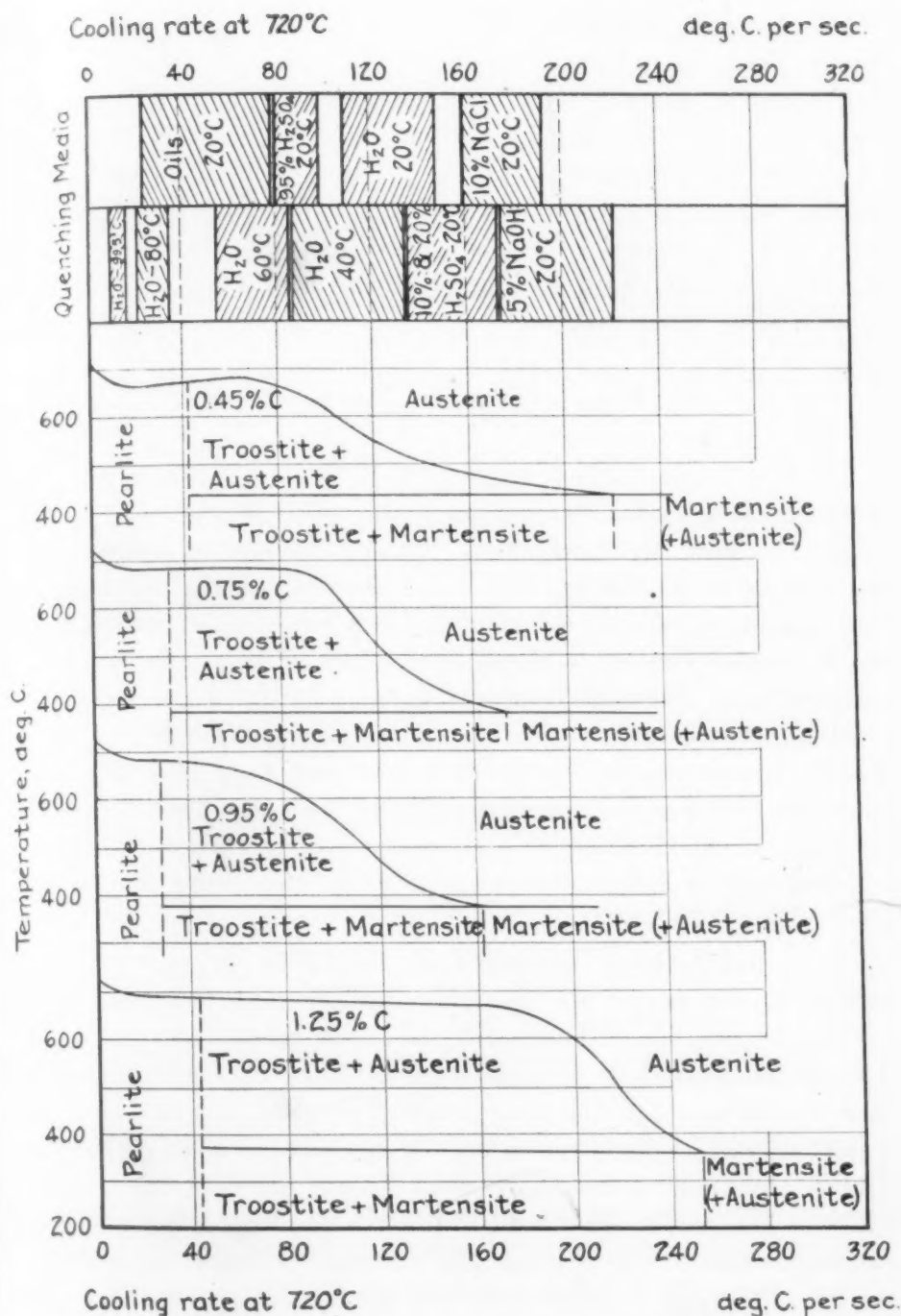
Fig. 17—Relation Between some Quenching Media for Heat Treatment and Quenching Diagrams for Carbon Steels.

quenching diagram was not as completely determined. There is also indicated the approximate range in cooling rates which may

be expected at the center of ½-inch diameter bars (of sufficient length to be free from "end effects") when quenched from temperatures between 810 and 875 degrees Cent. (1490 and 1607 degrees Fahr.) into various media. In all cases the highest cooling rates are associated with the highest quenching temperatures as the cooling velocity determined at a fixed point in the temperature scale increases with the initial temperature of quenching. Likewise a more rapid cooling results in a given solution when in motion than when still.

Water at Various Temperatures

It is at once evident from Fig. 17 that still water at a temperature just under the boiling point (99.5 degrees Cent.) takes away the heat so slowly that pearlite results in carbon steels. Still water at 80 degrees Cent. is a somewhat more rapid medium and produces pearlite or combinations of pearlite, troostite and small proportions of martensite depending upon the quenching temperature, chemical composition and initial condition of the steel under treatment. Still water at 60 or 40 degrees Cent. or water flowing past the steel at 1 foot per second at 20 degrees Cent. all give a troosto-martensitic product. However, the amount of martensite increases as the water temperature decreases, but in each case is likewise dependent upon quenching temperature, steel composition, etc.

It should be kept in mind that the described results were obtained at the *center* of ½-inch cylinders and that the cooling velocities and, hence, hardening, is much greater at the surface. This is illustrated in Fig. 18, which shows the center and surface hardnesses for the four steels quenched, as indicated into water at various temperatures. In no case is a fully hardened center obtained (martensitic steel free from troostite), a fact which is also clearly shown in Fig. 17 as the most rapid cooling in the water series is well below the critical cooling rate of all four steels. However, a fully hardened surface is obtained in water at 20 or 40 degrees Cent. and closely approximated by still water at 60 degrees Cent.

The inability to surface harden sizes as small as ½-inch by the use of water at temperatures above about 60 degrees Cent. is

not its only undesirable characteristic as a coolant.   As is well
known and shown for 0.95 per cent carbon steel in Fig. 19, the
most rapid cooling is obtained between 400 and 200 degrees Cent.
(752 and 392 degrees Fahr.) instead of, as in water between 20
and 40 degrees Cent., at higher temperatures where the steel is
better able to withstand stresses set up by thermal gradients.
Likewise a given change in water temperature between about 40
degrees Cent. and the boiling point has a much greater effect upon
cooling velocities than in water between 20 and 40 degrees Cent.
The changes in the latter case are very small and show no marked
sensitivity to temperature change.   However, it should be recog-
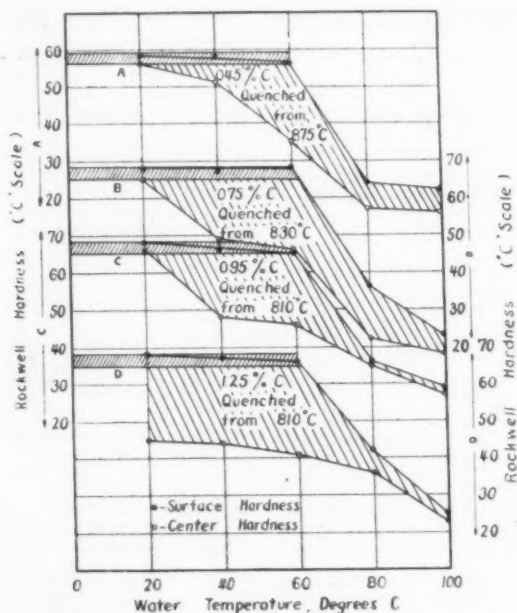
Fig. 18—Surface and Center Hardnesses Obtained in
½-inch Sections by Quenching Different Carbon Steels
into Water at Various Temperatures.   Finely Cross-
hatched Lines Represent the Hardness Obtained with
the Critical Cooling Rate.

nized that with certain combinations of steel composition, size and
shape of material and quenching temperature a cooling rate close
to the critical may be obtained, in which case small variations
in the temperature of the bath or other factors affecting to a
relatively small degree its cooling characteristics may produce
appreciable differences in the quenched steel.   This is not ex-
treme sensitivity of the quenching solution, but rather of the
steel under treatment, a distinction which should be kept in mind.
Thus where a fully hardened steel is desired at a given zone in

the cross section, a quenching solution should be chosen which will give a cooling somewhat in excess of the critical rate.

Oils at 20 Degrees Centigrade

Time-temperature cooling curves for the six oils referred to in Table II when used to quench 0.95 per cent carbon steel from 875 degrees Cent. (1607 degrees Fahr.) are reproduced in Fig. 20, and there is likewise given in Fig. 17 for comparison with the quenching diagrams of carbon steels, the approximate range in cooling rates to be expected with varying quenching temperatures between 810 and 875 degrees Cent. (1490 and 1607 degrees Fahr.). As a group, the oils are intermediate in cooling velocities between

Table II
Some Properties of the Quenching Media Used

Quenching Medium	Specific gravity at 15 deg. Cent.	Flash point, deg. Cent.	Fire point, deg. Cent.	Boiling point determinations			Parts per million of solids
				Initial boiling point, deg. Cent.	Final boiling point[5] deg. Cent.	Final vapor temperature deg. Cent.	
A. Aqueous solutions							
Washington, D. C. city water	....	...	...	...	...	...	132
Concentrated sulphuric acid[1]	1.840	...	...	...	...	...	...
10% sulphuric acid (by vol)[2]	1.069	...	...	...	...	...	...
20% sulphuric acid (by vol)[2]	1.143	...	...	...	...	...	...
10% sodium chloride (brine) (by wgt[3]	1.073	...	...	...	...	.	...
5% sodium hydroxide (by wgt)[4]	1.058	...	...	...	...	...	...
11.5% sodium hydroxide (by wgt)[4]	1.130	...	...	...	...	...	...
16.5% sodium hydroxide (by wgt)[4]	1.186	...	...	...	...	...	...
B. Oils							
Prepared No. 1	0.862	182	207	380	376	352	...
Cotton seed	0.915	321	362	402	360	300	...
Sperm	0.882	260	310	390	560	300	...
Neatsfoot	0.919	249	326	400	370	320	...
Prepared No. 2	0.874	190	212	375	375	345	...
Machine	0.909	207	243	395	395	355	...

[1]95% H_2SO_4.
[2]Prepared with c. p. concentrated (95%) sulphuric acid listed above.
[3]Prepared with crude commercial sodium chloride.
[4]Prepared with c. p. sodium hydroxide sticks.
[5]This is the equilibrum boiling temperature of the liquid as determined in a reflux flask under atmospheric pressure.

water at 40 and water at about 90 degrees Cent. However, they all give an extremely slow rate of temperature change below about 300 to 350 degrees Cent. (572 to 662 degrees Fahr.) in contrast with the rapid cooling in hot waters, already described. If, as is the case with the 0.95 per cent carbon steel the formation of martensite takes place at about 350 to 400 degrees Cent. it is probably largely tempered during the subsequent slow cooling. The

net result in ½-inch sections of 0.45 to 1.25 per cent carbon steels is the production of troostite with varying but small proportions of martensite, and either free ferrite or cementite depending upon whether the steel is respectively hypo- or hypereutectoid. Thus intermediate hardness values are obtained.

The use of oils also results in greater uniformity in microstructure and hardness throughout the cross section than is the case when using water at temperatures which give similar rates of cooling at 720 degrees Cent. (1328 degrees Fahr.). This is
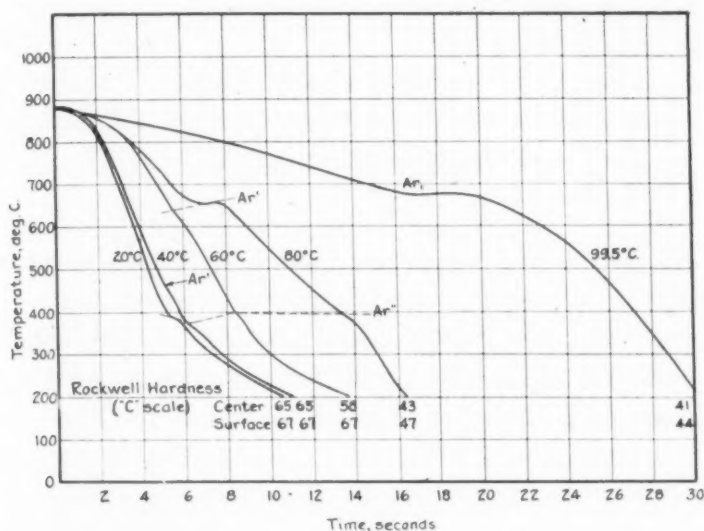

Fig. 19—Time-temperature Cooling Curves taken at the Center of ½-inch Diameter Cylinders of 0.95 Per Cent Carbon Steel when Quenched from 875 Degrees Cent. into Still Water at Different Temperatures.

clearly shown by comparison of the Rockwell hardness curves in Fig. 18 with values given in Fig. 20, and as might be expected from such conditions, a fully hardened surface was not obtained in any case.

The above discussion refers to oils kept motionless at 20 degrees Cent. but as shown by previous investigators and again confirmed by the authors in quenching experiments to be described later, variation in temperature at least up to 80 degrees Cent. has a very minor effect on the time-temperature cooling curves, so that the described effects apply within a somewhat wider field.

If, instead of a motionless quenching bath the oil flows past the specimen at 1.3 feet per second a slight acceleration in cooling is observed. This change is relatively unimportant in relation

to the foregoing tests, but may cause a considerable cha e in hardness and microstructure with certain combinations of quench- ing temperature, size and shape of material and steel composition. which bring the cooling rates within the "sensitive zones" (ab) or (cd) in Figs. 9 to 13 inclusive.

The six oils tested may be rated qualitatively in order of de- crease in "hardening power" (cooling velocity at 720 degrees Cent.)[5] as follows:

1. Prepared quenching oil No. 1
2. Cottonseed oil
3. Sperm oil   (Have almost identical cooling rat s at
4. Neatsfoot oil)720 degrees Cent. (1328 degrees Fahr.
5. Prepared quenching oil No. 2
6. Machine oil.

While the quenching properties of each of these oils are generally characteristic of the group as a whole and no very wide variations are observed except a rather rapid cooling at low temperatures in sperm and neatsfoot oils, other factors such as permanence in continued use and a high fire or flash point are of considerable practical importance and differences in these latter respects would materially affect the choice of any one oil in the group.

Sodium Hydroxide Solutions at 20 Degrees Centigrade

As a ready means of comparison, the approximate range in cooling rates is included in Fig. 17 for a motionless 5 per cent solution of sodium hydroxide in water at 20 degrees Cent. This is one of the most rapid of the quenching media studied and pro- duces a full martensitic structure throughout ½-inch sections in steels between about 0.75 and 1.00 per cent carbon quenched from temperatures between 810 and 875 degrees Cent. (1490 and 1607 degrees Fahr.). The same results may be obtained in steels close to the eutectoid composition when using the somewhat lower hard- ening heats ordinarily employed in commercial practice for small sections; in the 0.45 per cent carbon steel the highest tempera-

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[5]The terms "hardening power" or "hardening ability," as used in this report, refer to effects produced on the thermal transformations, microstructure and hardness of carbon steels by different media under otherwise comparable conditions of treatment. They are general in nature and considered to be proportional (qualitatively) to cooling velocity at 720 Degrees Cent. (1328 Degrees Fahr.). Thus the higher this cooling velocity, the higher is the "harden- ing power."

tures in the specified range are necessary for complete martensi-
tization, while even under these favorable hardening conditions
a troosto-martensitic structure containing appreciable proportions
of troostite results in steel containing 1.25 per cent carbon. This
latter result is undoubtedly due to the fact that 875 degrees Cent.
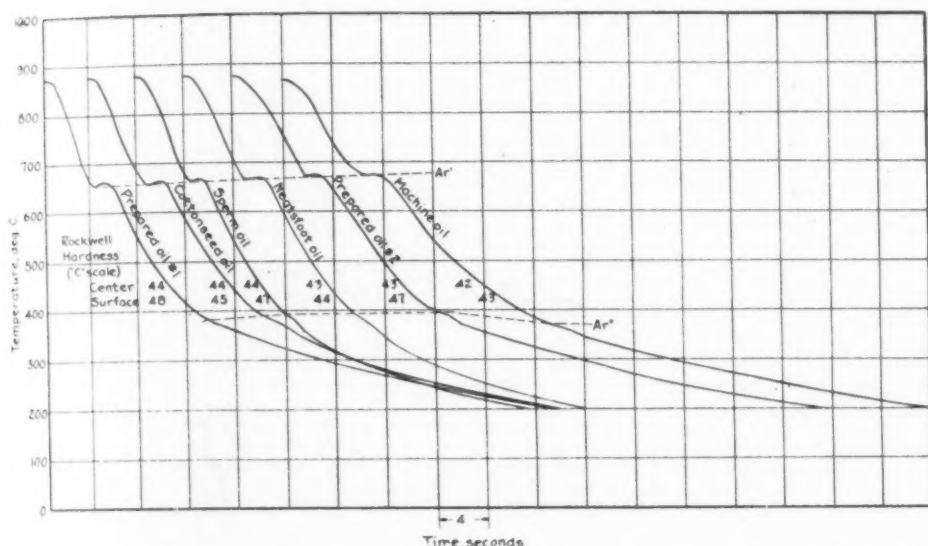(1607 degrees Fahr.) with short heating times is below the com-

Fig. 20—Time-temperature Cooling Curves taken at the Center of ½-inch Diameter
Cylinders of 0.95 Per Cent Carbon Steel when Quenched from 875 Degrees Cent. into
Various Oils Motionless at 20 Degrees Cent.

plete solution temperature of the excess cementite, thus leaving
nuclei very favorable to troostite precipitation during cooling.

In addition to higher cooling velocity in the range about 700
degrees Cent. (1292 degrees Fahr.) the sodium hydroxide solu-
tions "bite" more quickly than water, i. e., they begin to extract
heat at a rapid rate from the steel almost immediately after im-
mersion (Compare Figs. 21 and 19) instead of showing the defi-
nite initial period of comparative "quiescence" of water.

The rapidity with which cooling gets under way, a property
also characteristic to a somewhat lesser degree of dilute sulphuric
acid and brines, permits the use of lower hardening heats par-
ticularly in the treatment of high carbon or tool steels and is, of
course, most desirable from many view points. One of the prin-
cipal disadvantages is the maintainance of a high cooling velocity
to very low temperatures below Ar". However, it is not difficult
to minimize to a considerable degree tendencies for the steel to

crack under such conditions by making use of the common prac-
tice of removing the material from the quenching bath before it
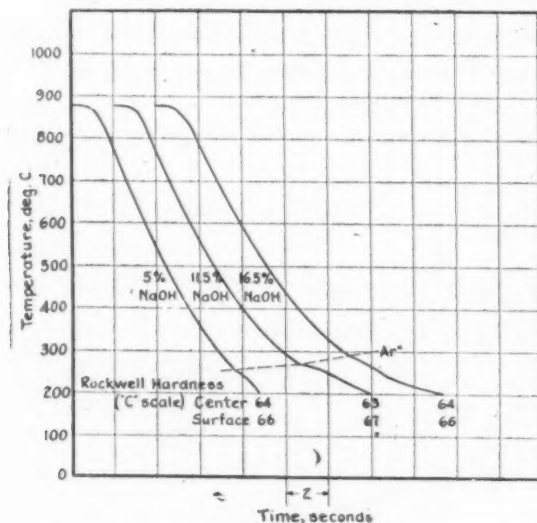reaches room temperatures and either allowing it to cool in air

Fig. 21—Time-temperature Cooling Curves taken at
the Center of ½-inch Diameter Cylinders of 0.95 Per
Cent Carbon Steel when Quenched from 875 Degrees
Cent. into Various Sodium Hydroxide Solutions at 20
Degrees Cent. Moving at 1 foot per second.

or immersing in hot water or in an oil bath held, say, between
100 and 200 degrees Cent. (212 and 392 degrees Fahr.).

Not a great deal of difference is observed in the cooling curves
for various concentrations of sodium hydroxide between 5 and
about 17 per cent (Fig. 21). The changes are of such a magni-
tude that it is difficult to make distinctions from the tests so far
carried out either with respect to concentration of the solutions
or the rate of motion. Without doubt, considerable latitude may
be permitted in the change in concentration which would ordi-
narily be encountered in continuous use, without materially af-
fecting results.

Sulphuric Acid Solutions at 20 Degrees Centigrade

Concentrated sulphuric acid without motion at 20 degrees
Cent. is intermediate between the oils and water under similar
conditions of heat treatment and results in a troosto-martensitic
structure in 0.95 per cent carbon steel as indicated in Fig. 17
(refer also to the cooling curves in Fig. 22). However, the hard-

ness as in the case of water at 20 or 40 degrees Cent. is practically identical with a completely martensitized steel.

Ten to 20 per cent sulphuric acid in water at 20 degrees Cent., either still or in motion at 1 foot per second, is somewhat more rapid as a cooling medium than water but appreciably slower than
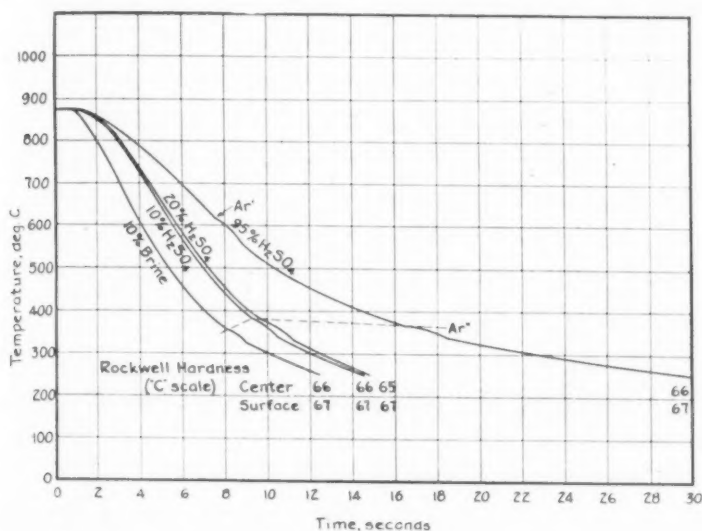
Fig. 22—Time-temperature Cooling Curves taken at the Center of ½-inch Diameter Cylinders of 0.95 Per Cent Carbon Steel when Quenched from 875 Degrees Cent. into Sulphuric Acid of Various Concentrations or 10 Per Cent Sodium Chloride Solutions Motionless at 20 Degrees Cent.

the sodium hydroxide solutions already discussed. Change in acid concentration from 10 to 20 per cent has a negligible effect upon the cooling curves, resultant center or surface hardness and microstructure of the ½-inch sections. The cooling velocities at relatively low temperatures, in the neighborhood of 200 to 400 degrees Cent. (392 to 752 degrees Fahr.) are slightly higher than in water and the magnitude of this increase is about the same as that obtained around 700 degrees Cent. (1292 degrees Fahr.). Full surface hardening is readily obtained with these solutions but only with favorable combinations of steel composition and quenching temperature is a martensitic steel free from troostite developed throughout the ½-inch section.

Sodium Chloride Brines at 20 Degrees Centigrade

Various concentrations of sodium chloride, between 10 per cent and saturation, in water at 20 degrees Cent. (brines) may,

as a group, be considered intermediate between 10 per cent sulphuric acid and 5 per cent sodium hydroxide solutions. However, they overlap the range in cooling rates (Fig. 17) for the somewhat slower dilute sulphuric acid and the more rapid sodium hydroxide and give cooling velocities well above water. With favorable conditions with respect to quenching temperature and motion of the bath, it is possible to fully harden to the center of $\frac{1}{2}$-inch round sections, steels from about 0.60 to 1.05 per cent carbon; the same result may be more readily attained by the use of relatively low hardening heats in alloys close to the eutectoid composition. However, in any of the steels considered, a fully hardened surface is quite easily obtained. A typical cooling curve for 10 per cent sodium chloride is shown in Fig. 22 in comparison with sulphuric acid of various concentrations.

GENERAL DISCUSSION AND CONCLUSIONS

There evidently exists a marked difference in opinion between various investigators as to the proper basis of comparison for quenching media. Pilling and Lynch (10) selected the cooling velocity at 700 degrees Cent. (1292 degrees Fahr.) as a measure of "quenching power" of liquids which was defined as the ability to absorb heat rapidly. Fry, (7) in experiments with large axles, based comparisons on the average cooling rate in a definite temperature interval which differed somewhat for the several quenching baths used. Mathews and Stagg (3) used the cooling time between 650 and about 370 degrees Cent. (1202-698 degrees Fahr.), which is fundamentally the same method used by Fry. Matsushita (16) considered the "turning point" or lowering and splitting of the transformations, as indicated by dimensional changes, a measure of the "hardening power," while LeChatelier (1), Lejeune[6] and Benedicks (2) compared cooling times, generally over the range 700 to 100 degrees Cent.; Portevin and Garvin (9) used the interval from 700 to 200 degrees Cent.

These methods of comparison fall into three main groups as follows: (1) Cooling times over a fixed temperature range, (2) Cooling velocity at a fixed temperature and (3) relation of the quenching media to the lowering of the transformations. No one

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[6]Refer to reference (1).

of these is entirely satisfactory but some are better than others. For example, the hardness, microstructure and thermal transformations in 0.95 per cent carbon steel are very nearly the same when quenched in water at 80 degrees Cent. as in neatsfoot oil but the cooling times over the range 700 to 200 degrees Cent. are respectively 12 and 29 seconds. These latter values show that water at 80 degrees Cent. has more than twice the "quenching power" of neatsfoot oil and without additional information it might reasonably be expected to have a much greater "hardening power." In reality, these two liquids produce almost the same degree of hardening under the described conditions.

Discussions in previous sections of this report show that the lowering of the transformations cannot by itself be a direct measure of "quenching power" because observed changes of this nature are characteristic of the steel under treatment and dependent as well upon hardening temperature, size and shape of material, etc. When quenching a ½-inch diameter section of 0.75 per cent carbon steel from 830 degrees Cent. (1526 degrees Fahr.) into water at 20 degrees Cent. two thermal transformations are observed (at center of section) respectively at about 520 and 360 degrees Cent. (968 and 680 degrees Fahr.) ; in water at 40 degrees Cent. these points occur at about 670 and 380 degrees Cent. (1238 and 716 degrees Fahr.), the first being located at a somewhat higher temperature than in the previous case. On the other hand, when quenching steel containing 1.25 per cent carbon under similar conditions, two thermal arrests are observed at about 675 and 385 degrees Cent. (1247 and 725 degrees Fahr.), whether the steel is immersed in water at 20 or 40 degrees Cent. If "quenching power" is judged solely by the lowering of the transformations, then water at 20 degrees Cent. would have a materially higher value than water at 40 degrees Cent. when based on the determinations with 0.75 per cent carbon steel and the same "quenching power" when based on the experiments with 1.25 per cent carbon steel.

Obviously these variations are associated with a change in steel composition and not due to any marked change in the inherent cooling characteristics of the water, so that comparisons of this nature do not define "qenching power" of liquids but rather "hardening power" with respect to a particular steel and section.

The cooling velocity at a temperature in the neighborhood of 700 degrees Cent. (1292 degrees Fahr.) is not an accurate measure of "quenching power" if this is considered to be the ability of a liquid to absorb heat rapidly. However, it is quite satisfactory, for designating the relative "hardening ability" of various quenching media with respect to carbon steels and, therefore, can be used as the principal variable in the construction of the "quenching diagrams" already described. That these relationships hold is a coincidence and largely due to the fact that a fairly uniform rate of cooling (except for heat effects of the transformations) is maintained by all aqueous solutions and oils listed in Table II throughout the range which largely, though not entirely, controls the degree of hardening; at least the majority show no abrupt and marked changes in rates within this range, which extends from around 720 degrees Cent. (1328 degrees Fahr.) to temperatures quite close to the beginning of martensite formation (Ar'' of the quenching diagrams).[7] However, it should be kept in mind that the entire time-temperature cooling curve must be considered for any quantitative comparisons but without also having quantitative data concerning mass effects with the various solutions such numerical values as may be obtained are of little more use than general comparisons based on cooling velocity at 720 degrees Cent. (1328 degrees Fahr.).

As shown in the quenching diagrams, progressive increase in the rapidity of cooling in the range about Ar_1, (700 degrees Cent.) causes a widening or splitting of this transformation into two heat effects Ar' and Ar'' and subsequently disappearance of the former. These represent respectively the zones of formation of troostite and martensite and since the properties of the quenched steel largely depend upon the relative proportions and general character of these constituents, it is logical that the cooling velocities in these two zones should be of particular importance. When the initial cooling around 700 degrees Cent. (1292 degrees Fahr.) is such that large proportions of troostite and only small proportions of martensite are formed, the cooling velocity in the neighborhood of Ar'' is relatively unimportant in determining the degree of hardening in the steel. When sufficiently rapid so that martensite becomes the predominant factor, the cooling velocity in the neigh-

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[7] The quenching temperature must be sufficiently high so that the initially slow cooling has been passed before the specimen reaches about 720 Degrees Cent. (1328 Degrees Fahr.).

borhood of Ar" is of greater importance but changes in this region
will not exert nearly as great an influence as equal changes in rate
around 720 degrees Cent. (1328 degrees Fahr.). Only in cases
of "interrupted quenching," in which the steel is removed from
the quenching bath at temperatures between Ar' and Ar", so that
an abrupt and marked retardation in cooling velocity is obtained,
will a very large change in degree of hardening be observed. As
such effects are not produced in any of the media studied, the cool-
ing rates about Ar" may be disregarded for qualitative comparisons
and "hardening ability," represented by cooling velocity at 720
degrees Cent. With these features in mind a general grading of
the various media may be made in order of increase in "harden-
ing ability," as shown graphically in Fig. 17.

Probably the most important conclusions to be drawn from the
described tests are as follows:

1. Quenching diagrams, in which are shown the relations be-
tween cooling velocity at 720 degrees Cent. (1328 degrees Fahr.)
and the thermal transformations, are similar in form for steels
varying from 0.45 to 1.25 per cent carbon. As the cooling rate
increases Ar_1 is at first gradually and slowly lowered and then
widened or split into two heat effects at widely different tempera-
tures. The upper one, called Ar' and coincident with the forma-
tion of troostite, occurs at first at relatively high temperatures,
while the lower point, Ar", at which martensite is formed, is ob-
served between 375 and 435 degrees Cent. (707 and 815 degrees
Fahr.), depending upon the carbon and manganese contents. With
further increase in cooling speed the lower point increases in in-
tensity (this denotes the formation of increasing amounts of mar-
tensite) but remains at approximately the same temperature, while
the upper decreases and is at the same time lowered until its tem-
perature of occurrence approaches that of Ar". With sufficiently
rapid cooling only the low point is observed and a martensitic or
"completely hardened" steel is obtained. The cooling velocity
which first results in a martensitic steel free from troostite is
called the "critical cooling rate."

The nature of these effects has long been known but the dia-
grams differ in at least one important detail from the usual con-
ceptions covering carbon steels, and as far as the authors are aware
represent a more complete determination than has so far been

published. At least in some quarters it has been considered that a sharp discontinuity existed at the critical cooling rate and that Ar' was not lowered very materially before it disappeared abruptly in favor of Ar''. That such an effect, already reported for air hardening steels, is not observed in commercial carbon steels when quenching from within and slightly above the ordinary hardening temperature range, is quite clearly shown in Figs. 9 to 15 inclusive.

The customary terminology has been used in discussing the quenching diagrams merely as a matter of convenience for demonstrating the effects of various coolants on some of the properties of carbon steels. It is not to be inferred that the authors agree to the conception of a true splitting of Ar₁ as the designated positions of Ar' and Ar'' may merely represent the maximum speed of reactions in a transformation range which has widened materially. However, such theoretical considerations are removed from the purpose of either the report or the described tests.

2. Steel in the neighborhood of the eutectoid composition (0.85 per cent carbon) has a critical cooling rate of about 160 degrees Cent. (320 degrees Fahr.) per second; increase or decrease in carbon raises this materially so that in steels containing 0.40 or 1.25 per cent carbon the critical rate is about 250 degrees Cent. (482 degrees Fahr.) per second. Thus steels in the neighborhood of the eutectoid composition are more readily hardened than either higher or lower carbon steels, for they become martensitic and free from troostite with much slower cooling under otherwise comparable conditions of treatment.

3. In the steels containing 0.75 per cent or more of carbon, the Rockwell hardness increases with the cooling rate until fairly large proportions of troostite are present. It then remains practically constant over a well defined range until cooling has been sufficiently rapid to make martensite the predominating factor when it again increases. Above the critical cooling velocity and within the limits investigated, the hardness remains nearly constant. In 0.45 and 0.25 per cent carbon steels the "step" in the hardness curves is less distinct and as the carbon becomes lower a more gradual increase in hardness with cooling velocity is observed.

4. Steels from 0.75 to 1.25 per cent carbon cooled at rates slightly below the critical contain small but appreciable porportions of troostite and show the same Rockwell hardness (within limits of experimental methods employed), as those which are completely martensitic. As these two structural types are known to show material differences in certain types of performance involving abrasion or wear resistance, indentation hardness tests of commercial accuracy will not always insure correct or satisfactory heat treatment.

5. No single numerical value selected from time-temperature cooling curves will give a quantitative measure of the "hardening ability" of various quenching media; such comparisons require consideration of the entire cooling curve. However, for all the aqueous solutions and oils tested, the cooling velocity at 720 degrees Cent. (1328 degrees Fahr.) permits a general grading consistent with results produced in quenched carbon steels in ½-inch sections. With this in mind the various liquids studied increase in "hardening ability" in the following order:

> Water at 99.5 degrees Cent. (211.1 degrees Fahr.)
> Water at 80 degrees Cent. (176 degrees Fahr.) and the various oils at 20 degrees Cent. (68 degrees Fahr.)
> Water at 60 degrees Cent. (140 degrees Fahr.)
> 95 per cent sulphuric acid at 20 degrees Cent. (68 degrees Fahr.)
> Water at 40 degrees Cent. (104 degrees Fahr.)
> Water at 20 degrees Cent. (68 degrees Fahr.)
> 10 per cent sulphuric acid at 20 degrees Cent. (68 degrees Fahr.)
> 10 per cent sodium chloride at 20 degrees Cent. (68 degrees Fahr.)
> 5 per cent sodium hydroxide at 20 degrees Cent. (68 degrees Fahr.)

6. None of these showed extreme sensitivity productive of erratic results when kept in fairly vigorous motion about the steel. However, if the section is such that a cooling velocity close to the critical is produced in the zone which is to be hardened, great difficulty will be encountered in securing consistently uniform results

with ordinary methods of heat treatment. This is not extreme sensititvity of the quenching solution but of the steel under treatment in relation to definite cooling rates. Thus where a fully hardened steel is desired at a given zone in the cross section a coolant should be chosen which will give in that zone a cooling velocity somewhat in excess of the critical rate. If the chosen liquid will likewise cool extremely rapidly at the lower temperatures the steel can be removed from the quenching bath before it is entirely cold and so minimize any increase in the tendency to crack. However, it is quite evident that media having "hardening ability" greatly in excess of that required for the work in view, should not be used.

7. In addition to a higher cooling velocity in the range which largely determines the degree of hardening in carbon steels dilute sodium hydroxide solutions "bite" more quickly than water, i. e., they begin to extract heat at a rapid rate from the steel almost immediately after immersion instead of showing the definite initial period of comparative "inaction" of water. The same characteristic, but to a somewhat lesser degree, is shown by the dilute sulphuric acid solutions and brines and permits the use of lower hardening heats for high carbon steels, with advantages attending such procedure. However, these media maintain relatively high cooling rates at low temperatures where the steel is least able to withstand stresses induced by thermal gradients.

8. The six oils studied show some variations in "hardening ability" but not of such magnitude as to be of much importance in the heat treatment of carbon steels except in very small sections or those which bring the cooling rates within the sensitive zone below the point at which A_1 first widens or splits. Other factors, such as permanence, which was not studied in this investigation, might more largely affect any choice than demonstrated differences in the cooling curves. In comparison with water, brines, dilute sulphuric acid or sodium hydroxide solutions, they give very slow cooling at temperatures below about 375 degrees Cent. (707 degrees Fahr.). In this latter range cooling was most rapid in the sperm and neatsfoot oils.

9. Rise in temperature of water generally reduces its "hardening ability" but this change becomes greater as the temperature

approaches the boiling point. Between 20 and about 45 degrees Cent. the effects are small and no marked variation is observed in the characteristics of the cooling curves. A somewhat greater variation results for a given temperature rise between 45 and 60 degrees Cent. but in the range from 60 to 99.5 degrees Cent. the differences are very large and a marked change also takes place in the character of cooling. As is well known, the initially slow rates in the neighborhood of 700 degrees Cent. (1292 degrees Fahr.) are followed by high cooling velocities at temperatures between 200 and 400 degrees Cent. (392 and 752 degrees Fahr.).

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THE MACROSCOPIC EXAMINATION OF STEEL

By V. O. Homerberg

Abstract

This paper explains the manner in which segregation takes place in steel. The method of preparing the specimens, the formulas of the etching reagents, together with directions for their use and the necessary precautions to be taken, are given. Macrographs are included to illustrate the results obtained from the use of these different reagents.

THE RESULTS of the chemical analysis of a piece of steel are based on the assumption that the elements present are uniformly distributed to form a homogeneous material. The same restrictions obtain for a mechanical investigation. The method used to determine whether or not this uniformity exists is based on the examination of the material at a low magnification, i. e., either with the unaided eye or with a simple magnifier after polishing and etching. This so-called *macroscopic examination* has several advantages over a microscopic one, which it should precede in a great many cases, in that the preparation of the sample for examination is much simpler. Much larger areas may be examined and the interpretation of the results is easier than is the case with a microscopic examination. Generally the polishing is carried through No. 000 emery paper.

A macroscopic examination of material gives information as to what has taken place in the ingot mold, by showing the presence of any segregated areas, and also the flow lines in material that has been forged. A microscopic examination gives information as to heat-treatment and composition.

Mechanism of Segregation

In order to understand the manner in which segregation may occur in steel, it is necessary to consider the mechanism through which selective solidification takes place. In the case of a pure metal, the temperature at which the material solidifies remains constant. If, however, we chose such a material as steel, we shall have to take into consideration the effect of the presence of other elements, such as carbon, phosphorus, sulphur, etc. Carbon exists in solution as such, or as iron carbide, phophorus as iron phosphide, and sulphur as manganese sulphide, provided sufficient manganese is present.

When a mold is filled with liquid steel, the metal immediately in contact with the mold will solidify first, since the heat loss at this point is the greatest. The crust thus formed fixes the external dimensions of the ingot. As solidification proceeds inwardly, successive layers freeze progressively, and a shrinkage cavity forms in the upper central part of a normally cooled ingot. This is due to the decrease in volume of the metal in passing from the liquid to the solid state. Such a shrinkage cavity is known as a *pipe*.

Impurities in a substance lower its melting or freezing point, provided that these impurities are soluble in the substance when in the liquid state. This lowering of the temperature, at which solid material separates from the liquid, proceeds as the concentration of the impurities in the solution increases.

Fig. 1a shows the equilibrium diagram of the iron-carbon alloys, and illustrates this principle. AC is a line drawn through the temperatures at which solid material begins to separate from the liquid, the temperature varying with the carbon content. AB is a line drawn through the temperatures below which the material is in the solid state. The compositions of the solid, separating from the liquid and of the remaining liquid, can be determined at any given temperature within the solidification range by drawing a horizontal line through this temperature so as to intersect the lines AC and AB. For example, at the temperature (t) the composition of the solid will be represented by the point (f) and will be approximately 0.60 per cent carbon, while the composition of the residual liquid will be represented by the point (g) or approximately 1.60 per cent carbon, although the carbon content

of the liquid to start with was 0.85 per cent. These compositions
of solid and liquid at temperature (t) are determined by noting
the points of intersection with DE of the vertical lines drawn
from points (c) and (d).

The important points to be noted in the study of this diagram
are that the solid material that separates with the gradual de-
crease in temperature, becomes enriched in carbon and that the
liquid from which it separates also becomes enriched in carbon
and is at all times higher in carbon content than the solid, which
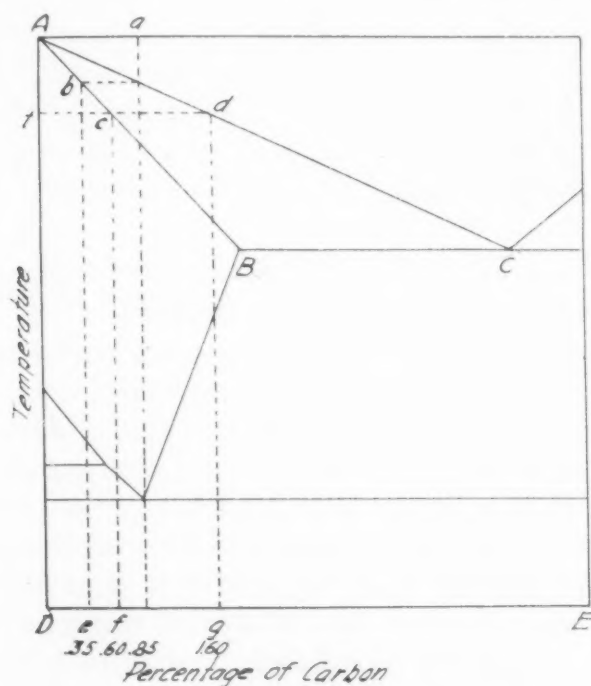
Fig. 1a--Iron-Carbon Equilibrium Diagram.

separates from it. The same procedure is followed in considering
phosphorus. Therefore, the material immediately in contact with
the ingot mold contains the least amount of carbon, phosphorus
and sulphur.

Fig. 1 shows the manner in which solidification takes place in
two types of molds.[1] Fig. 2 shows the steel ingots resulting from
the use of these two types. The shrinkage cavity in each case is
clearly visible. The concentration of the elements carbon, phophorus

[1]Figs. 1 and 2, taken from "The Heat Treatment of Tool Steel," by Brearley. Permis-
sion of Longmans, Green and Co.

and sulphur increases gradually and reaches a maximum in the region of the *pipe*.

DENDRITES

The manner in which crystallization takes place[2] is shown in Fig. 3. The crystals form at right angles to the walls of the ingot
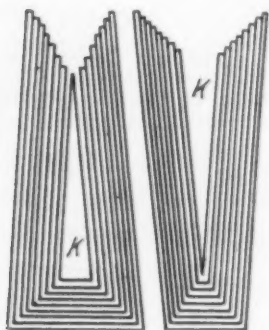
Fig. 1   Fig. 2
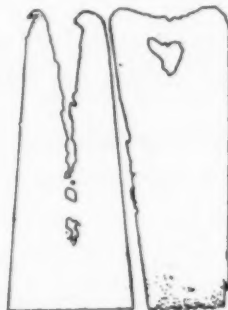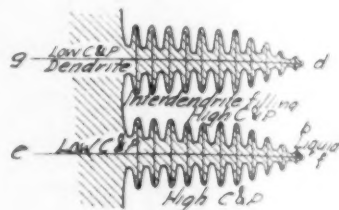
Fig. 1—Shows a Diagram of the Manner in which Steel Freezes in Taper Molds. Fig. 2—Sketch of Small Steel Ingots Cast in Taper Molds. Fig. 3—Shows a Diagrammatic Sketch of the Formation of a Dendritic Structure During Solidification.

mold. The solid material with the least amount of carbon, phosphorus and sulphur is at the point (e), with increasing amounts toward the tip (f), and to the tips of the branches. Such a development is known as a dendrite, a conglomeration of which gives rise to what is known as a *dendritic* or *pine-tree* structure. The interdendritic filling contains a higher percentage of carbon, phosphorus and sulphur than the dendrites themselves. Also, the quantities of these elements increase toward the upper central part of the ingot so that the last liquid to solidify will contain the largest amounts of these elements.

In this dendritic solidification, impurities are very often entrapped by the dendrites. The formation of a vast number of very small and closely packed dendrites creates small local segregates, thereby favoring their removal by diffusion and by mechanical work. Rapid and quiet solidification creates this condition.

Although the interdendritic filling is higher in carbon, phosphorus and sulphur than the dendrites themselves, the carbon begins to diffuse immediately after solidification so that the carbon content of the two tend to become the same. Two of the characteristics of phosphorus are its tendency to segregate and

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[2]Metallography of Steel and Cast Iron, by Howe. Permission of McGraw-Hill Book Co.

the great difficulty with which this segregation is eliminated. Therefore, the phosphorus content between any two dendrites or in the interdendritic filling remains practically the same after solidification and after passing through the transformation range. The sulphur is present as manganese sulphide provided there is sufficient manganese present. This compound is insoluble in the solid material and, therefore, does not possess the property of diffusion. It is entrapped by the dendritic branches or is mechanically pushed ahead into the last portions of the solidifying liquid.

Fig. 4 is a photograph of the dendrites present in a section of an ingot, which was polished and then etched with Stead's reagent.[3] The close packing of the dendrites next to the ingot mold is to be noted. Although these dendrites are approximately at right angles to the walls of the mold, they become elongated and parallel in the subsequent rolling and forging operations and give rise to *fibre* in steel.

The structure of a broach that fractured in hardening is shown in Fig. 5. The hardening operation was correctly performed, and the chemical analysis was satisfactory. The macro-structure clearly shows the presence of the original ingot structure, which had not been broken down by mechanical work. A micro-examination also revealed the presence of an excessive amount of slag inclusions.

It is obvious from the discussion given above that a sufficient amount of the ingot, to include the shrinkage cavity or pipe, must be discarded. Gases are evolved when the steel passes from the liquid to the solid state. These gases bubble through the liquid and escape. If a crust is allowed to form on the top, these gases cannot escape except into the *pipe*, thereby enlarging it and causing it to extend farther into the ingot.

Sometimes it occurs that the pipe is not completely removed and gives evidence of its presence in bars or in the fabricated articles. This pipe, upon being exposed to the air while hot, becomes coated with iron oxide, which prevents it from being welded together when mechanically worked. The photograph in Fig. 6 shows the presence of a *pipe* in a bar, which failed in forging. A wrench jaw that was forged, subsequently broke into two parts.

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[3] The reagents that may be used to determine the macrostructure of steel, together with their compositions and the methods of application, are enumerated in the appendix of this paper.

The two parts held together along the outer edge only. The fracture of this specimen is shown in Fig. 7.
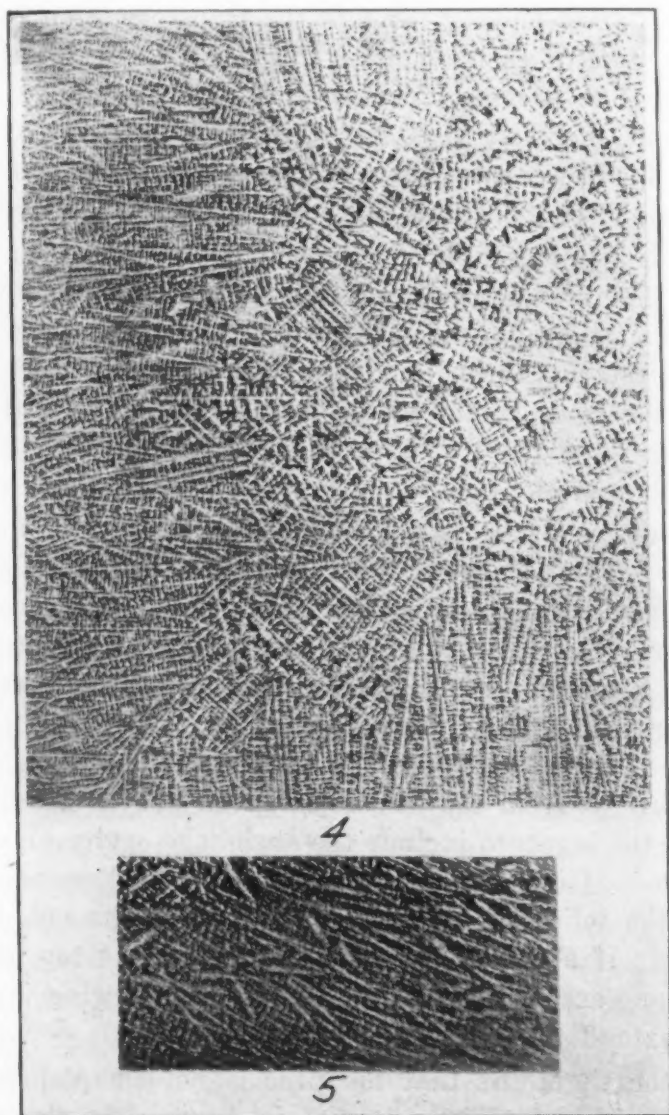
Fig. 4 — Macrograph of a Dendritic Structure in a Steel Ingot, Etched with Stead's Reagent. x 2.5. Fig. 5—Shows a Similar Structure in a Broach, Etched with Stead's Reagent. x 2.5.

Very often the gases that are evolved in the process of solidification become entrapped to form blowholes. Since these blowholes are filled with reducing gases, i. e., mainly carbon monoxide and hydrogen, they are capable of being welded on forging or rolling. If, however, these blowholes are externally situated so that they
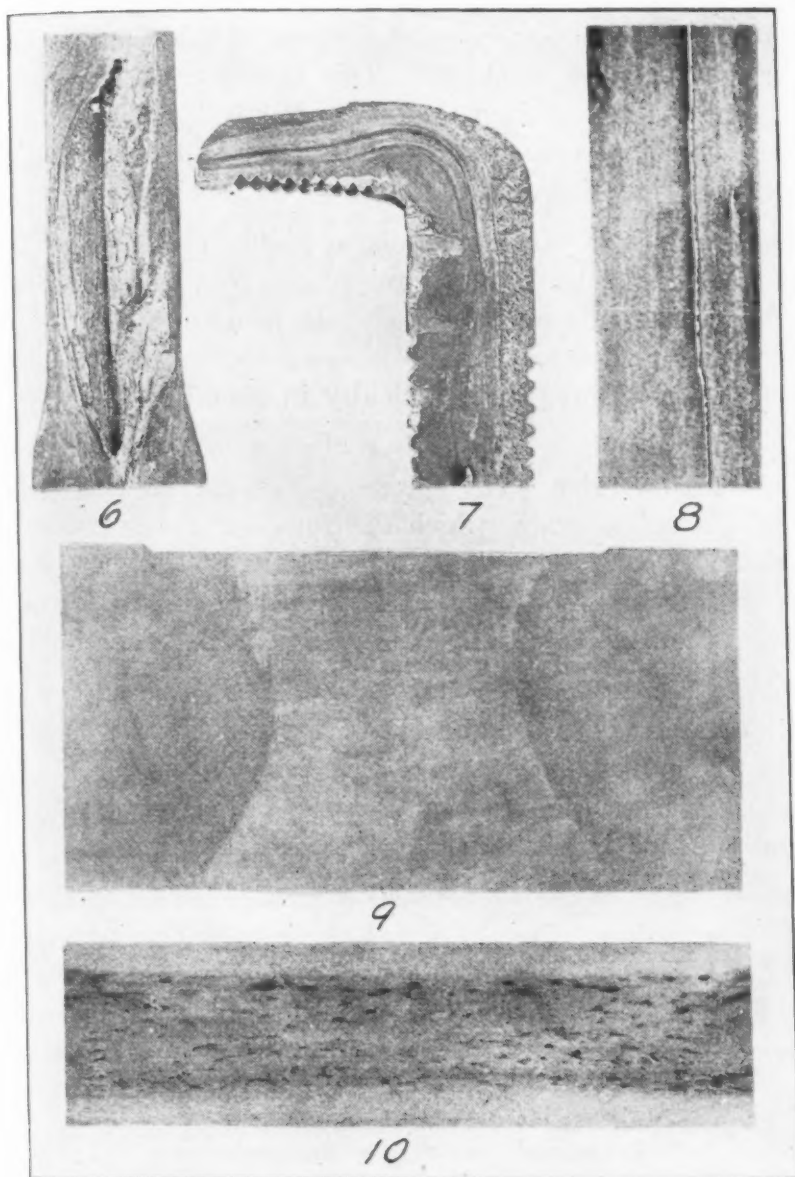
Fig. 6—Photograph of a Pipe in a Forging. x 0.75. Fig. 7—Photograph of a Wrench Jaw which Shows the Presence of a Pipe. x 0.5. Fig. 8—Shows a Seam in a High-Speed Steel Tool Bit. x 2. Fig. 9—Shows a Thermit Weld Etched with Heyn's Reagent. x 0.5. Fig. 10—Shows the Segregation in a Mild Steel, Etched with Ammonium Sulphate. x 0.5.

become exposed to the air and thereby become coated with iron oxide, they are incapable of being welded, and become elongated in the direction of rolling, giving rise to *seams*. Fig. 8 shows a *seam* in a high-speed tool bit.

Fig. 9 is a photograph of a thermit weld, etched with *Heyn's solution.* The contrast in color between the low carbon and the higher carbon areas is shown. This macrograph shows, furthermore, that the molten iron that was produced as the result of the thermit reaction, has melted the ends of the two bars being welded, forming the junction indicated.

Ammonium persulphate has been highly recommended by Dr. Rawdon of the Bureau of Standards.[4] This recommendation is well deserved as the solution is easy to prepare and to apply and gives excellent results. Fig. 10 shows a segregated area in a low carbon steel that gave great difficulty in machining.

The photograph in Fig. 11 is that of a section of a steel shaft that failed in service. The specimen was etched with the *iodine reagent.* A spiral crack, which developed at the segregated ring, extended the entire length of the shafting. Drillings from the center and from the outside edge showed a satisfactory analysis. However, the segregated area analyzed 0.23 per cent phosphorus.

Stead's reagent gives excellent results when used for the detection of phosphorus segregation. It has, however, the disadvantage that the specimen must be well polished. The photograph in Fig. 12 shows streaks or *ghost lines*, indicative of phosphorus segregation, in a longitudinal section.

Canfield[5] has recently proposed a new reagent to detect phosphorus segregation. Fig. 13 shows the results obtained with this reagent. A method for making a *phosphor print* is also considered. Fig. 14 is such a print in which the blue streaks represent the areas of segregation. In the halftone these reproduce as dark lines.

SULPHUR AND OXIDE SEGREGATIONS

The detection of sulphur segregation is best determined by the sulphur print method. Fig. 15 shows clearly the dark sulphide area, which appears originally as a dark sepia tone.

The segregation of oxide is shown by the *LeChatelier and*

[4] Use of Ammonium Persulphate for Revealing the Macrostructure of Iron and Steel, by Henry S. Rawdon. *Scientific Papers* of the Bureau of Standards. No. 402.

[5] *Chemical and Metallurgical Engineering.* Vol. 30, No. 12, p. 470.
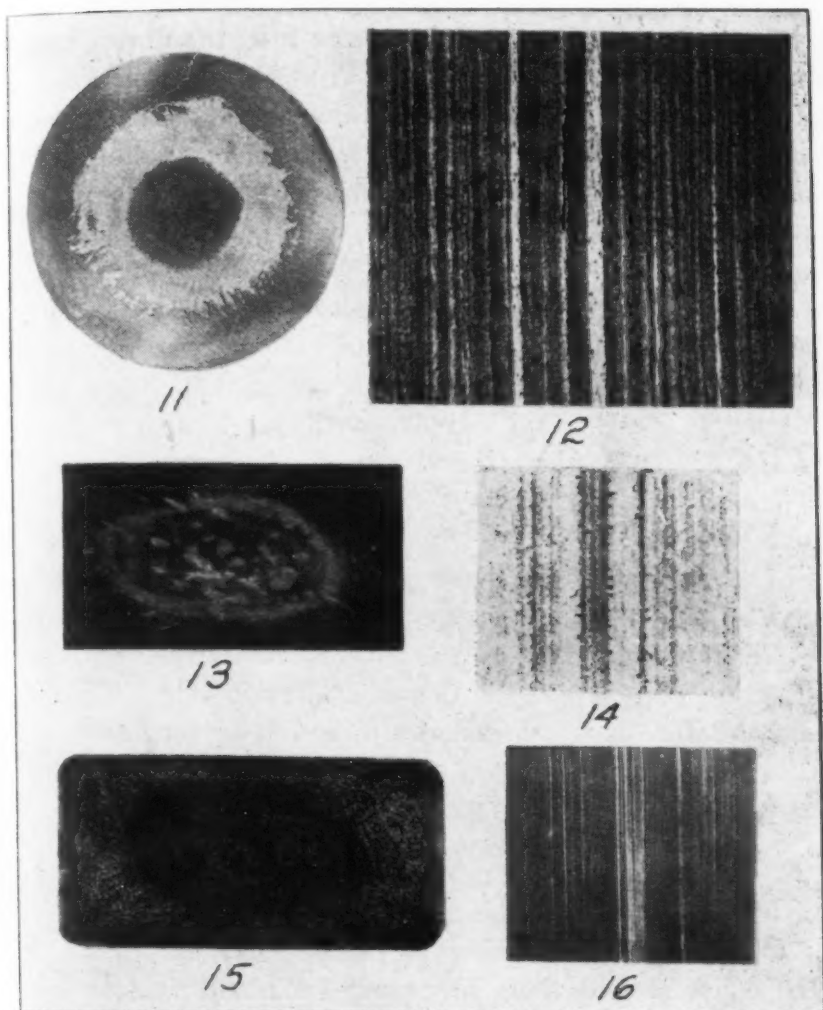
Fig. 11—Photograph Showing Phosphorus Segregation in a Steel Shaft. Etched with Iodine Reagent. x .5. Fig. 12—Ghost Lines in Steel Etched with Stead's Reagent. x 4. Fig. 13—Shows Phophorus Segregation as Etched with Canfield's Reagent. x 1. Fig. 14—Phosphorus Print as Etched with Canfield's Reagent. The Dark Lines originally Appear as Blue Lines. Fig. 15—Sulphur Print. This Appears as a Dark Sepia on the Original Impression. Fig. 16—Shows Oxide Streaks Etched with LeChatelier and Dupuy's Reagent. x 0.5.

Dupuy reagent. Fig. 16 shows streaks that supposedly represent this segregation, although these streaks are also shown with Stead's reagent.

FIBRE IN STEEL

A study of fibre in steel is of great importance, particularly in the manufacture of such articles as crankshafts, gears and other

forgings. A crankshaft, for example, may be fabricated so as to cause the fibre to produce a *snaky* grain, i. e., the fibre follows the direction of forging or, it may be roughly cut out and then machined to the desired shape, whereby the fibre will produce a straight-grained structure. Fig. 17 shows a crankshaft that has been properly made in which the "snaky" grain is present. Fig. 18 shows a machine-forged crankshaft, which also reveals this structure. Fig. 19 shows a crankshaft which has been improperly made. A crankshaft made in such a manner that the applied stress will be perpendicular to the direction of the fibre will have far greater shock-resisting properties than one that has been made in such a manner that the applied stress will be parallel to the direction of the fibre. A normal fracture in a crankshaft takes place at the point (a) as shown in Fig. 17. However, in the case of a structure such as in Fig. 19, it will take place at the point (a), thereby following the path of least resistance. *Humfrey's reagent* was used to etch these specimens.

Fig. 20 shows a section of a crankshaft that was deeply etched with a boiling 20 per cent solution of sulphuric acid. The manner in which the fibre has followed the direction of forging is clearly shown.

CONTACT PRINTING

Instead of photographing deeply-etched specimens, a reproduction of the details may be made by contact printing. A small amount of printer's ink should be placed on a glass plate and a squeegee roller should then be passed back and forth a number of times until the ink has been uniformly distributed over the roller. The ink is then transferred to the specimen. The specimen should then be pressed firmly against a sheet of thick white paper, whereby the details of the etched surface will be reproduced. Fig. 21 is a macro-print of the specimen shown in Fig. 20.

METHODS OF GEAR MANUFACTURING

Two of the methods for manufacturing gears[6] are shown in Figs. 22 and 23. Fig. 22 illustrates the *flat-bar* method, in which the blow of the hammer is perpendicular to the direction of the fibre. The behavior of the fibre is shown in Fig. 26. A tooth cut

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[6] Figs. 22, 23, 24 and 25 from Report on the Materials of Construction used in Aircraft and Aircraft Engines. British Aeronautical Research Committee, pp. 28 and 29.
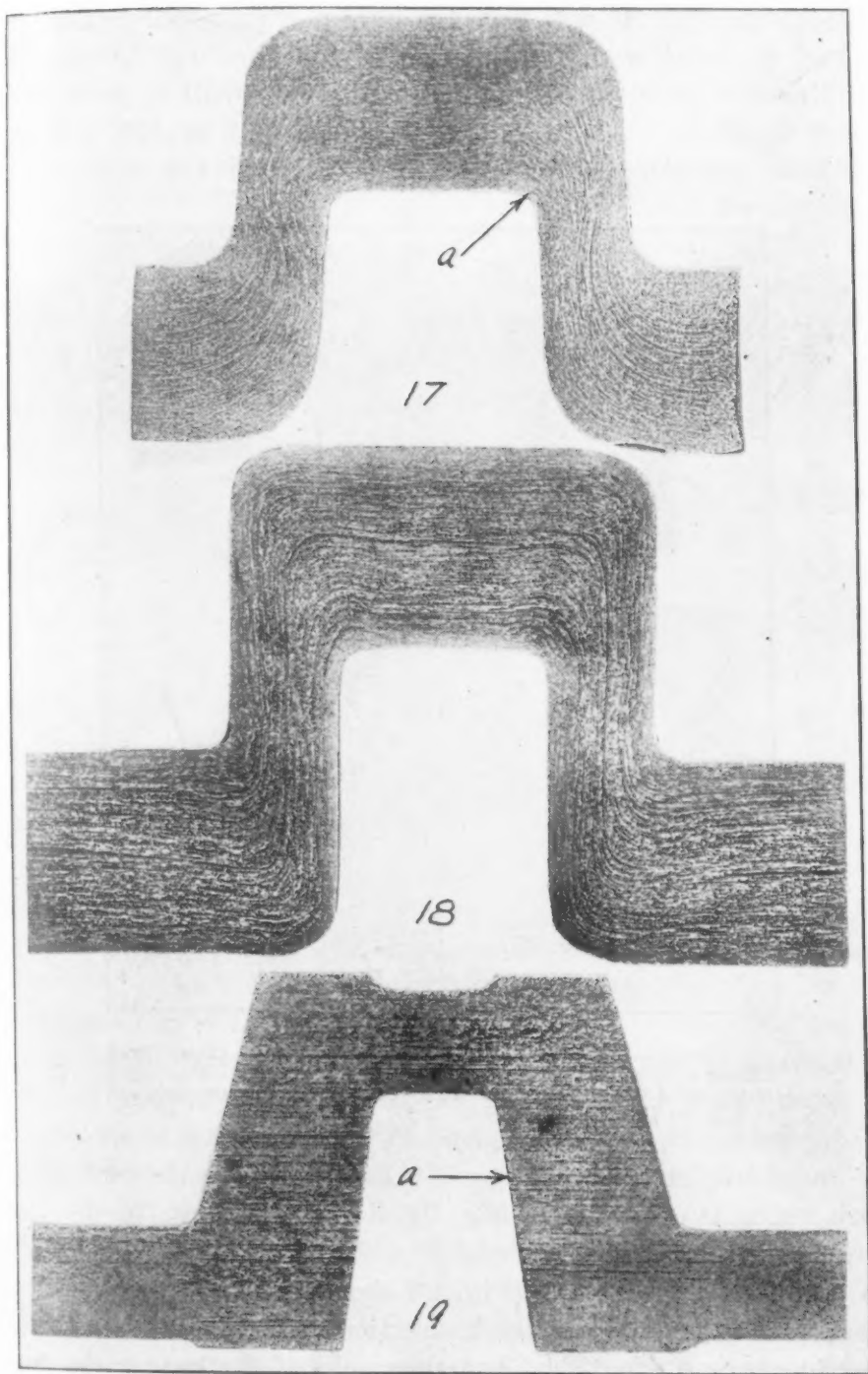
Fig 17—Macrostructure of a Crank Shaft Showing a Snaky Grain, Etched with Humfrey's Reagent. x 0.5. Fig 18—Shows a Machine-Forged Crank Shaft, Having a Similar Structure to that of Fig. 17. x 0.5. Fig. 19—Straight-Grained Crank Shaft, Etched with Humfrey's Reagent. x 1.

at point (A) or (B) will have the fibre perpendicular to the pitch
line of the tooth and the direction of the fibre will be such that
the direction of the stress applied to the tooth will be perpendicu-
lar to the fibre.   A tooth cut at the point (C) or (D) will have
the fibre parallel to the pitch line and to the direction of
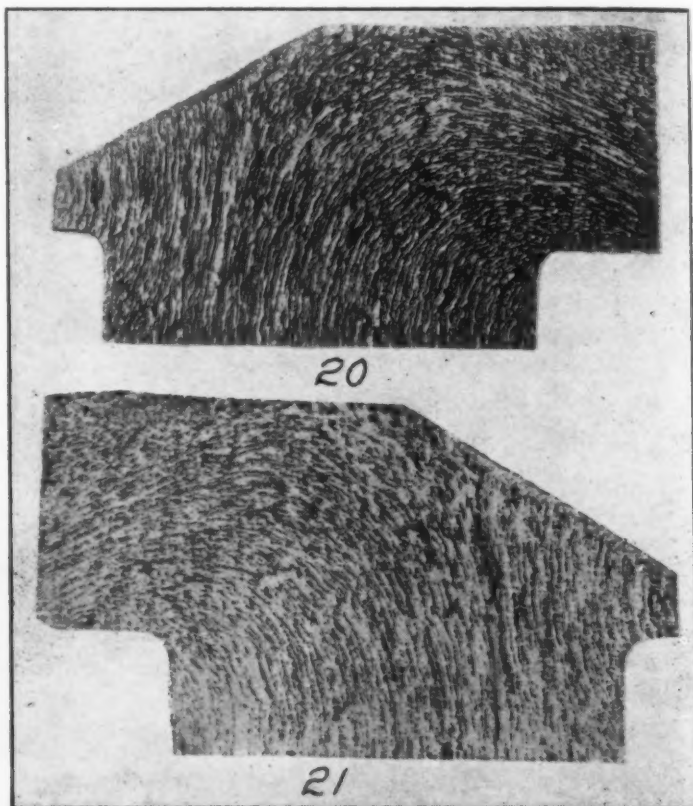
Fig. 20—Shows a Snaky-Grained Deep Etched Crank Shaft
Etched with 20 per cent Sulphuric Acid. x 1.   Fig. 21—Macroprint
of this same Crank Shaft Obtained by Contact Printing the Specimen
of Fig. 20 Using Printers' Ink.   x 1.

the applied stress and will be greatly inferior in its
shock-resisting properties.   Fig. 24 shows the grain in the teeth
at the points (A) and (B) and Fig. 25 the grain in the teeth at
the points (C) and (D).   Fig. 23 shows a gear blank made by
the *up-ending* method, in which a section of a bar is chosen so that
its diameter is a great deal less than that of the gear to be made
from it.   A blank is then made by applying the blows of the ham-
mer in a direction parallel to that of the fibres in the original sec-
tion.   The fibres will then be caused to radiate from a common

center, so that all of them will be perpendicular to the pitch line of the teeth and to the direction of the applied stress. Every tooth in the gear will, therefore, have maximum shock-resisting properties and will be superior to a gear made by the *flat-bar* method. The structure of a gear made by the *up-ending* method is shown in Fig. 27. *Humfrey's reagent* was used for etching.
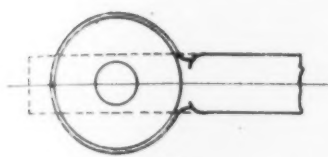
Fig. 22
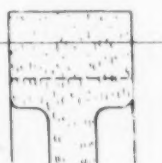
Fig. 24
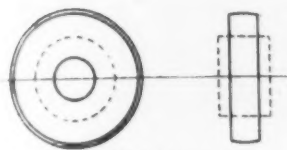
Fig. 23
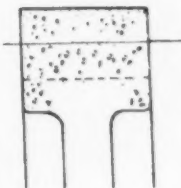
Fig. 25

Fig. 22—Shows a Sketch of the Flat-Bar Method of Forging Gear Blanks. Fig. 23—Shows the Up-Ending Method of Forging Gear Blanks. Fig. 24—Shows the Grain in the Teeth of the Gear at the Points A and B of Fig. 26, made by the Flat-Bar Method. Fig. 25—Shows the Grain in the Teeth of the Gear at the Points C and D of Fig. 26, made by the Flat Bar Method.

Forgings that have been etched with Humfrey's reagent to show the behavior of the fibre are shown in Figs. 28 and 29.

One of the most common expressions used in accounting for fractures in crankshafts and similar articles is that the failure is due to the *crystallization* of the steel. This erroneous idea undoubtedly originates from the appearance of the fracture, known as a *detail fracture* or a fatigue failure, although a better term would be that of a *progressive failure,* produced as the result of alternations of stresses, in which part of the fracture appears more or less smooth and the remainder granular or crystalline. The steel to begin with is crystalline. If a piece of steel is subjected to a single stress, it will fulfill its requirements indefinitely, provided that a certain limit is not exceeded. This stress may be either tension, compression or torsion. If, however, the material is subjected to stresses of similar values of compression and tension but repeatedly alternated, the article may ultimately fail. An example, to illustrate this point, is shown in Fig. 30. This specimen represents a section of a 2-inch shafting that was sub-
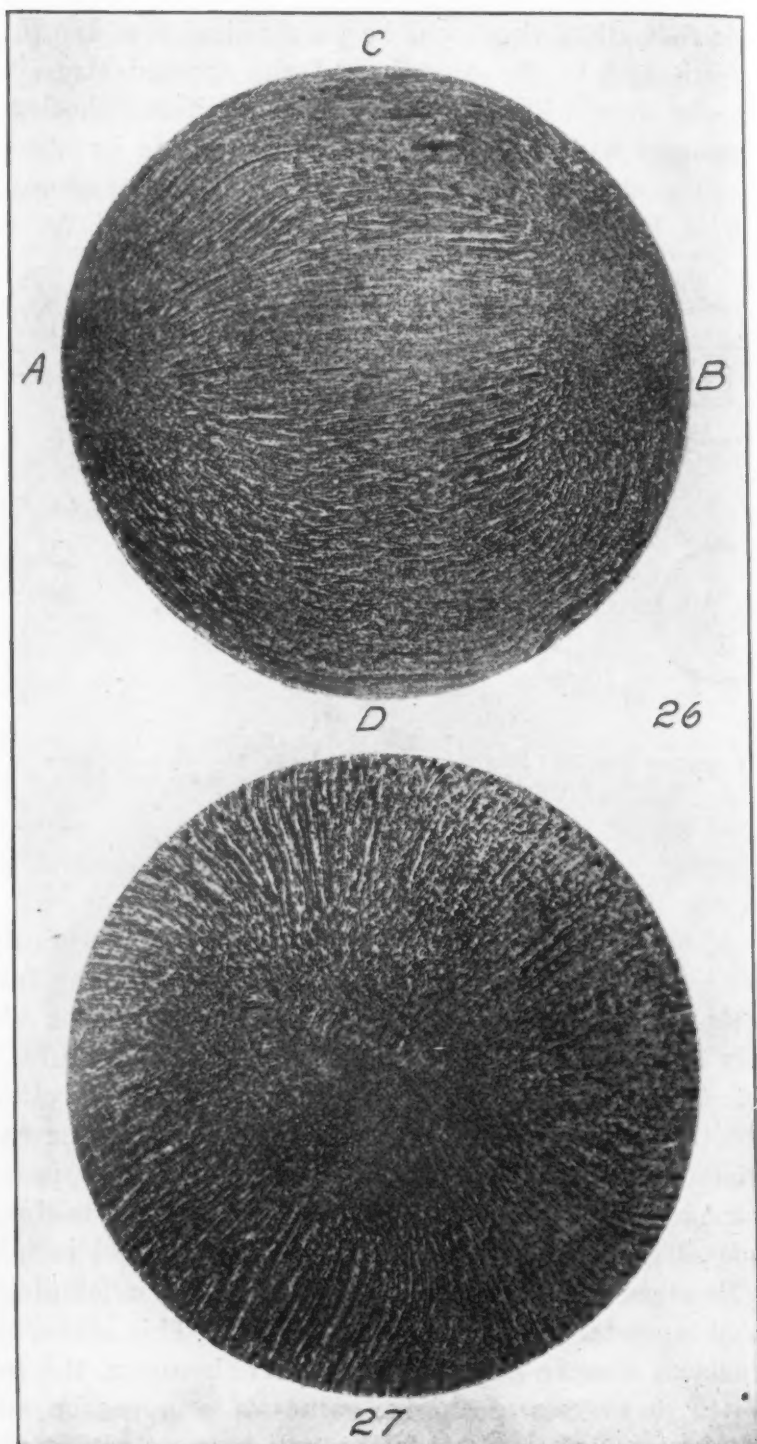
Fig. 26—Shows a Deeply Etched Gear Blank made by the Flat-Bar Method. Etched with Humfrey's Reagent. x 0.75. Fig 27—Deeply Etched Specimen of a Gear Blank Made by the Up-Ending Method, Etched with Humfrey's Reagent. x 0.75.

28

29
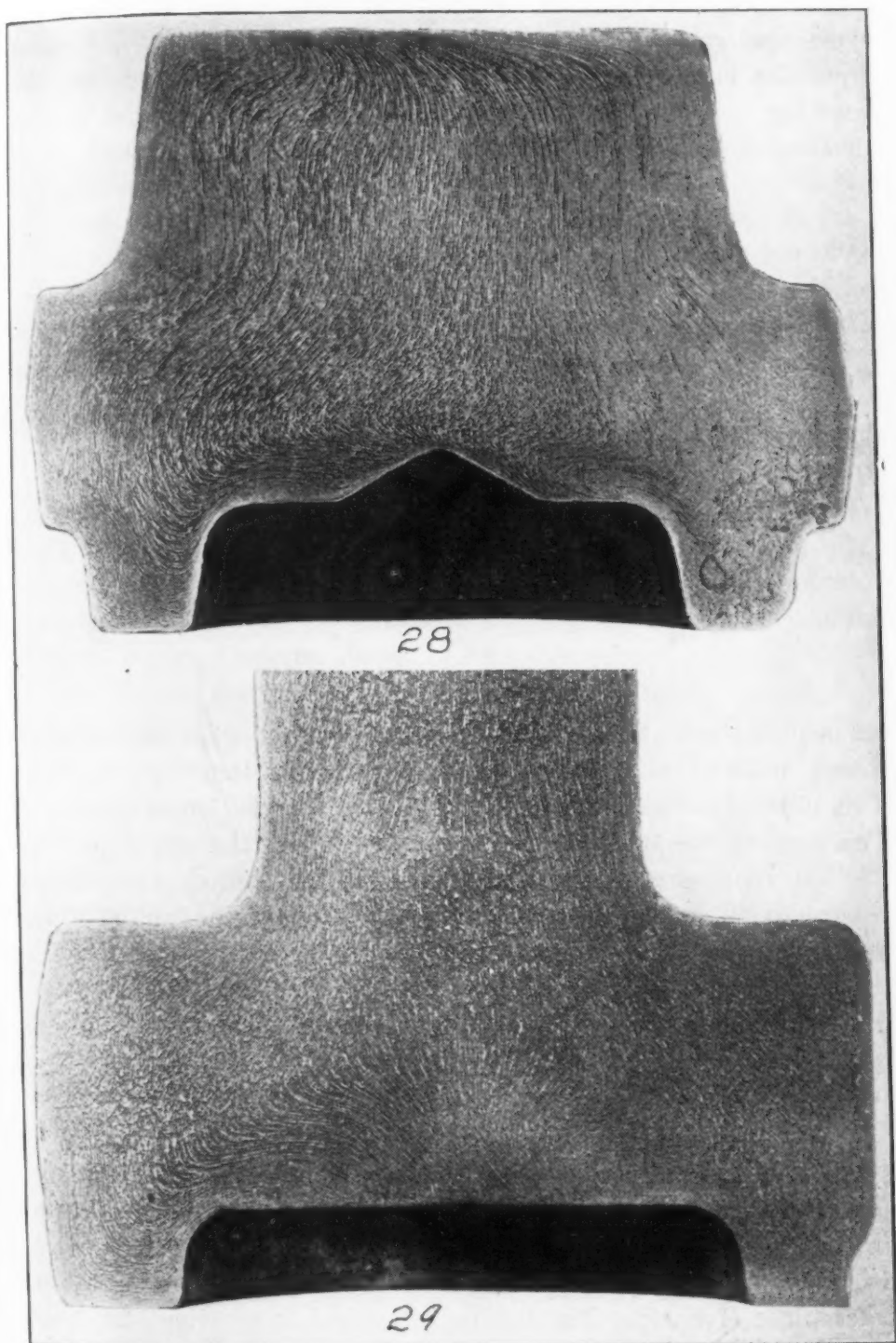
Fig. 28—A Deeply Etched Forging Etched with Humfrey's Reagent.   x 0.75.   Fig. 29—
Another Deeply Etched Forging Etched with Humfrey's Reagent.   x 1.

jected to alternations of tension and compression in which the cycle was repeated thousands of times. A small crack started from the base of a V-thread and gradually penetrated into the shafting. Gradually the usefulness of the cross-section of the shafting decreased until finally a point was reached at which so
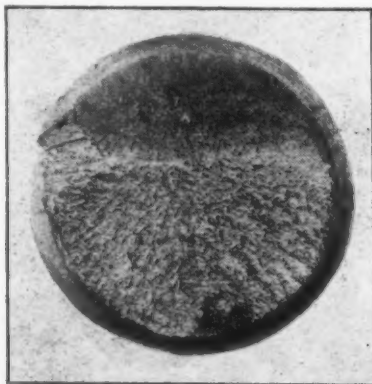
Fig. 30—Detail or Progressive Fracture. x 0.5.

much of its usefulness had been destroyed that what remained as sound material was unable to withstand the final load applied. This part of the section, the lower part in Fig. 30, broke suddenly. The part of the shafting that appears smooth, the upper part in Fig. 30, represents the part of the section that failed gradually or progressively, while the granular part indicates the sudden fracture. A microscopic examination showed the same structure over the entire cross section. The prevalent idea that steel crystallizes when subjected to alternations of stresses should be dismissed.

Cracks in Steel

The presence of cracks in steel may be detected by two methods. One method is to etch the specimen, preferably well polished, with an etching solution colored with a dye. The surface is then quickly dried and the point at which the oozing of the colored solution takes place is noted. The magnetic method is excellent for tools and similar articles in order to detect very fine cracks before subjecting the tools to expensive finishing operations.

APPENDIX

Preparation of Specimens

In most cases specimens should be polished through No. 00 or No. 000 emery paper. A well polished surface, such as for microscopic examination, is preferred whenever Stead's reagent or that of LeChatelier and Dupuy is employed. The writer has found it advantageous to etch the specimen deeply with a 10 per cent solution of ammonium persulphate after polishing through 1G paper and then to pass directly to No. 000 paper before etching with the final reagent. All the specimens that were etched with Humfrey's reagent were prepared in this manner. This procedure is convenient in the case of large specimens.

In photographing deeply etched specimens, apply printer's ink to fill all of the hollows and then polish the reliefs with No. 000 emery paper. Excellent contrast will thus be obtained. Other specimens should receive a thin film of a light machine oil or glycerin, before photographing.

The method for reproducing the details of etched surfaces by macro-printing has been described elsewhere in this article. It should be remembered that the light portions in a macro-print represent the hollows in the deeply-etched specimen.

MACROSCOPIC ETCHING REAGENTS

Stead's Reagent

Cupric chloride	10 grams
Magnesium chloride	40 grams
Concentrated hydrochloric acid........	20 cubic centimeters
Alcohol, sufficient to make.............	1000 cubic centimeters

Dissolve salts in smallest possible quantity of hot water (about 25 cubic centimeters), then add the acid and the alcohol.

Cover the specimen with a thin layer of the reagent. Shake off the layer of liquid after it has acted for one minute and replace it with a fresh portion of the acid mixture. Repeat the operation until the desired results have been obtained, then wash first with hot water and finally with alcohol. Copper will deposit first on the phosphorus-free areas, so that the light areas represent phos-

phorus segregation. The specimen should be well polished. If the deposit becomes discolored it may be brightened by rubbing briskly with a dry swab of cotton. See Figs. 4, 5 and 12.

LeChatelier and Dupuy Reagent

Cupric chloride	1 gram
Picric acid	0.5 gram
Water	10.0 cubic centimeters
Concentrated hydrochloric acid	1 to 3 cubic centimeters
Alcohol	100 cubic centimeters

Use in same manner as Stead's reagent. Copper will deposit on the oxide-free areas first. See Fig. 16.

Canfield's Reagent

Nickel nitrate	5.0 grams
Cupric chloride	1.5 grams
Ferric chloride	6.0 grams
Hot water	12.0 cubic centimeters
Methyl alcohol	150.0 cubic centimeters
Nitric acid	1.0 cubic centimeters

Dissolve salts in the hot water, add acid and then the alcohol.

Cover the specimen with the solution and allow to remain until the desired effects have been obtained. White areas represent phosphorus segregation. See Fig. 13.

A record of the result may be obtained by soaking a developing paper (matte finish) in a 5 per cent solution of potassium ferri-cyanide in water, laying it face up on a piece of blotting paper and then pressing the surface of the plated specimen against it, leaving it there for about a minute. The paper is then rinsed, fixed and washed in the usual manner. The areas that were not plated represent phosphorus segregation, and will be recorded blue. See Fig. 14.

Heyn's Reagent

Copper-ammonium chloride	10 grams
Water	100 cubic centimeters

Immerse the roughly-polished specimen in the solution, polished surface up. Care must be taken that the solution quickly covers the surface. Gently agitate the liquid. A coating of spongy copper forms over the face of the specimen. Remove this coating

with a swab of wet cotton. High carbon, sulphur and phosphorus areas will be darkened as a result of the etching.

This reagent is a convenient one to use for segregation in general. It keeps indefinitely and does not require a well-polished surface. See Fig. 9.

Humfrey's Reagent

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Copper-ammonium chloride ............ 100 grams
Concentrated hydrochloric acid....... 50 cubic centimeters
Water ............................... 1000 cubic centimeters
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Polish specimen through No. 00 or No. 000 emery paper. Cover the specimen or immerse it in the neutral solution (Heyn's reagent) first until a spongy deposit of copper has been obtained. Without removing this copper deposit, pour on Humfrey's reagent. Add fresh portions from time to time. Figs. 17, 18, 19, 26, 27, 28 and 29 indicate the macrostructures that were obtained by transferring the specimens containing the spongy deposit to a hot solution and allowing them to remain until the desired result had been obtained. If Humfrey's reagent is used directly without the preliminary treatment with Heyn's reagent, a copper coating will be obtained that adheres firmly to the specimen, thereby producing unsatisfactory results.

Iodine Reagent

```
Iodine .............................. 10 grams
Potassium iodide .................... 20 grams
Water ............................... 100 cubic centimeters
```

Dip pledget of cotton in the solution and swab repeatedly the well-polished surface of the specimen. This solution deteriorates on standing. Carbon and sulphur segregation will be indicated by dark-colored areas while phosphorus segregation will be revealed by lighter colored areas. See Fig. 11.

Ammonium Persulphate

```
Ammonium persulphate .............. 1 to 2 grams
Water ............................. 10 cubic centimeters
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The solution should be prepared just before use. Dip a cotton swab into the solution and then rub the surface of the specimen.

Use considerable pressure. A fine polish of the specimen is unnecessary, a finish on No. 00 or No. 000 emery paper being sufficient. An etching period from 1 to 2 minutes is usually sufficient. It is an excellent reagent to show variations in crystalline structure as well as segregation. See Fig. 10.

Acids

Acids of varying composition and mixtures are frequently used hot. The method most frequently used is to etch the specimen in a boiling solution of hydrochloric or of sulphuric acid containing 10 to 20 per cent of the acid. See Fig. 20.

Detection of Cracks

The roughly polished specimen is magnetized and then immersed in a light oil containing iron dust in suspension. Kerosene and *cast iron mud*, such as is obtained from lapping disks, may be used. The iron particles bridge across any slight discontinuity in the surface of the specimen and indicate accurately the system of surface cracks. The excess of iron rust must be removed by bathing the specimen in alcohol or clean kerosene.

Sulphur Printing

Velox, Azo, Cyko or other developing papers, having a matte finish, is soaked in a 2 per cent solution of sulphuric acid, then placed on a glass plate. The steel specimen is gently pressed upon the paper and then removed after about 30 seconds. The print is washed in water and fixed in *acid hypo* in the usual way. Sulphide areas are indicated by brown spots. See Fig. 15.

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STAINLESS STEEL AND STAINLESS IRON

By O. K. Parmiter

Abtsract

This paper reviews the history and development of stainless steel and stainless iron of the 13 per cent chromium type.

The author discusses the problems envolved in the manufacture of this material, its composition and the effect of various elements upon it. The heat treatment, forging, normalizing, annealing and hardening are covered in detail. Many of the physical properties of this material are reviewed, such as heat resistance, tensile properties, corrosion resistance, resistance to acids, solutions and gases.

The author has covered in some detail the general properties of stainless steel, including the brazing and welding, cold drawing and cold rolling, its cutting properties, electrical conductivity and resistivity, magnetic properties, machining qualities, microstructure and thermal conductivity.

A brief discussion of stainless iron and its applications and possibilities are included.

STAINLESS STEEL*

History

THE ADVENT of stainless steel has marked an epoch in the manufacture of tool steel, secondary only in importance to the introduction of high speed steel at the beginning of the present century. Although its development was somewhat retarded during the late war, its worth has now been fully proven under

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*The text of this paper on stainless steel is confined to material containing approximately 13.00 per cent chromium. No attempt has been made to compare it to the many other stain-resisting alloys and no discussion of such alloys or steels is intended.

actual service conditions and it has established itself as a valuable commercial steel.

The knowledge of the value of high percentages of chromium in imparting special properties to iron and steel has been known for many years. As early as 1872, the effect of chromium in producing non-corrosive properties in steel was described, vaguely, however, by two Englishmen, Woods and Clarke, in a provisional petition for a patent which was never granted. Their specification dealt with a low carbon steel, containing approximately 32.00 per cent chromium. Investigation as to the resistance which high chromium steels have for certain corrosive explosives used in ordnance work, was made by the Krupps at their factory in Essen, Germany, as early as 1895. Doctor Goldschmidt of thermit-fame, understood the resistance of such steels to heat and corrosion as well as the importance of low carbon. In an address made at Duesseldorf soon after the close of the Paris Exposition in 1900, Dr. Goldschmidt discussed the difficulties in manufacture, together with the properties and possibilities of the steel.

In 1900, an exhibit was made by Jacob Holtzer & Company at Paris on a series of steels, containing 0.40 per cent carbon with chromium running from 10.00 to 15.00 per cent. Complete metallurgical data accompanied this exhibit. About this time, a controversy concerning the quality of the alloy required for making this steel arose between the English firm of George G. Blackwell & Sons Company, and the German manufacturers, Goldschmidt Thermit Company. The merits of the two alloys, made by different processes for the same purpose, were ably discussed in the leading English, French and German industrial and metallurgical journals of the day.

During all this time, little use had been made of the known properties of the alloy, and although it was quite valuable, no important application had yet been made. Elwood Haynes in America and Harry Brearley in England were the first investigators to successfully apply the useful properties of this alloy steel to every day use. Working independently of each other, they made their discoveries at practically the same time. Both were granted patents on their claims in the United States Patent Office, the application of Haynes pre-dating that of Brearley by only a few weeks. Both applications were filed in March, 1915.

In the Haynes patent, the composition limits for carbon are stated as being between 0.10 and 1.00 per cent, with chromium from 8.00 to 60.00 per cent.

The composition limits set forth in Brearley's patent called for carbon under 0.70 per cent with chromium between 9.00 and 16.00 per cent. As a standard composition 0.30 per cent carbon; 0.30 per cent manganese; and 13.00 per cent chromium, was recommended. In justice to Brearley, we can say that in the past ten years this composition has not been improved upon and that it is yet the best balanced stain resisting steel for general every day purposes, although numerous attempts have been made to improve its quality by the addition of various elements or the slight alteration of those already present. Brearley also specifically stated that the steel should be made in the electric furnace, that it should be hardened and polished to give maximum results and that it was specially adapted to cutlery purposes. The truth of these statements has been proven many times since they were first written and today they stand out boldly with almost as much importance attached as the composition itself.

Although the Brearley and Haynes patents are the most important ones in the field, several others have been granted by the United States Patent Office. In the majority of cases with these latter patents silicon and nickel have been recommended as additional alloying elements. Some patentees advise the incorporation of carbon up to as high as 2.00 per cent. For certain purposes, several of these steels have some advantages, but for all uses where a balance between hardness and stain-resistance is to be maintained, no steel has yet been produced which shows distinct advantages over the standard 13.00 per cent chromium, stainless steel.

During the period of the war, difficulty was experienced in obtaining chromium due to the fact that the Government commandeered all of the material for war purposes. Little progress in the development of stainless steel was made during that time. Soon after the close of the war, however, rapid progress was made in perfecting methods of manufacture.

Manufacture

Of all the steels known at the present time, stainless steel is possibly the most difficult to produce satisfactorily. Not only is

the manufacturer confronted by unusual and extremely narrow composition limitations, together with a peculiar combination of "air-hardening" and "red-hardness" properties, which makes its working extremely difficult, but experience has shown stainless steel to be the most susceptible to surface seams, internal segregates, and non-metallic inclusions of any steel known to modern tool steel metallurgy.

The fabricators and users of this complex alloy tool steel were not long in appreciating quality and the extent to which stainless steel reflects the steel making ability of its maker. Not only were they interested in quality as regards the appearance and superior characteristics of the finished article, but also from the standpoint of profitable production. For instance, they soon learned that there was considerable difference in steel of the same analysis from two different sources. In this respect, stainless steel is an ideal example of distinctive character in tool steels of the same composition and, possibly, the foremost of all modern steels in reflecting the personal care and knowledge of its makers.

Although there has been very little departure from the original composition of the steel, a great deal of progress has been made in the development of soundness and uniformity, both with regard to the surface and internal structure of the steel. By constant care and extensive research, aided by years of experience in melting and working high grade tool steels, a stainless steel of superior quality has been developed, which has been accepted by the trade as a distinctive standard product. The development of this degree of perfection has marked progressive steps in the manufacture of the steel. Many former difficulties in the way of production of intricate shapes and sizes have been overcome and the steel can now be supplied in most of the commercial shapes possible with ordinary steel.

COMPOSITION AND EFFECTS OF VARIOUS ELEMENTS

The following limitations on chemical composition have been found to give the best all around results as regards hardness, stainlessness and general efficiency:

```
Carbon     ..............................  0.25 to 0.40 per cent
Silicon    ..............................      under 0.30 per cent
Managanese ..............................  0.25 to 0.35 per cent
Sulphur    ..............................      under 0.030 per cent
Phosphorus ..............................      under 0.030 per cent
Chromium   .............................. 12.50 to 14.50 per cent
```

Carbon

The usual carbon content found in stainless steel is 0.30 per cent, and this is considered standard. The useful range of the element, however, is very narrow. Under 0.25 per cent the steel will not harden successfully for cutlery, while above 0.40 per cent the steel is difficult to forge and loses considerable of its non-corrosive properties, unless special heat treatments are resorted to. The eutectic between carbon and chromium exists at about 0.30 per cent carbon and 13.0 per cent chromium. This composition gives the proper equilibrium or balance between these two elements as regards hardness and resistance to stain.

When the carbon is low, 0.15 per cent and under, the steel hardens with difficulty and, therefore, cannot be used for any purpose where a cutting edge is required. Such a composition forges much easier than the standard and is an ideal material for drop forging and stamping. It is needless to say that this low carbon material is rustless regardless of heat treatment if crystallization and distortion are kept at a minimum.

Silicon

Silicon in amounts in excess of 0.75 per cent raises the critical point, thereby necessitating the use of a higher hardening temperature. High silicon improves the rolling property of the steel. It also has the advantage of producing increased resistance to heat and gives better non-scaling qualities. It does not replace chromium in effecting resistance to stain and corrosion.

When considerable amounts of silicon are added to stainless steel, the brittleness of the steel is increased both in the annealed and hardened condition. High silicon also has a tendency to increase grain growth. It has been found by experience that the best results are obtained when the silicon is kept comparatively low.

Manganese

The effect of this element is very much the same as in carbon steel. It is advisable to keep the manganese content comparatively low, although a certain amount is necessary to assist in rolling and hardening.

Sulphur and Phosphorus

Sulphur and phosphorus are impurities and as such should be held as low as possible. They are especially injurious to stainless steel in that they induce electrolytic action, which causes corrosion. Sulphides occurring in the steel in appreciable amounts are oxidized to sulphites and sulphates, both of which have a detrimental effect. Non-metallic inclusions of slag and other impurities cause very troublesome pits.

Chromium

Chromium is the most important element in stainless steel, and is practically the only alloy used. It is from the chromium content that the steel derives its resistance to the various oxidizing and corrosive agents. Chromium combines with the carbon present to form carbides, which compound not only furnishes the requisite hardening properties, but is in itself one of the most difficult substances to oxidize.

HEAT TREATMENT

Forging

Stainless steel is more difficult to forge than ordinary carbon tool steel. In this respect it resembles high speed steel. Forging becomes more difficult as the carbon content is increased. Due to its low heat conductivity, stainless steel does not absorb heat readily, hence it is necessary to soak the steel at a low temperature, in the vicinity of 1300 degrees Fahr., for a long period of time as a preliminary measure to insure softness and uniform heating for forging. Between the temperatures of 1700 and 2000 degrees Fahr., stainless steel can be forged without danger of rupture, but below 1700 degrees Fahr., the steel forges with difficulty and if forcibly deformed at this temperature by heavy blows, excessive strains and breakage will be the result. Frequent reheating is, therefore, recommended.

Stainless steel is an air-hardening steel, and if allowed to cool in the air from its forging heat, it becomes hard. Just how hard the steel will be, depends, aside from its composition, upon the

temperature to which it has been previously heated and also upon the cross section of the finished product. The hardness may vary to a considerable extent. For instance, it may correspond to a Brinell number as high as 550 if the initial heating temperature was between 1700 and 2000 degrees Fahr. or to a Brinell number of only 250 if the annealed steel is forged from a temperature not over 1400 degrees Fahr. Again, if an excessively high forging temperature is used, such as one in excess of 2200 degrees Fahr., the steel is burnt, an "austenitic" structure is formed, and the resultant forged mass is soft but brittle and shows a Brinell number in the vicinity of 300. This condition is ofttimes present in the tips of knife blades which have been heated downward in an open furnace.

It is, therefore, evident that no general use should be made of the resultant hardness of air-cooled forgings. Attempts to hammer knife blades and thin sections until they are black, with the object of making them hard and resilient, should be discouraged, as results obtained are not only very unreliable as regards uniform hardness, but the material is in a highly stressed condition and likely to break with the least provocation. Forgings made in this manner usually rust or corrode. Many failures in knife blades, have been traced to this source.

On account of its red hardness and air-hardening properties, stainless steel does not lend itself readily to drop forging and stamping. It can be drop forged, but temperatures considerably in excess of those generally used and frequent reheatings are necessary. All work must be trimmed while hot or annealed prior to trimming, if cracking and splitting are to be avoided.

Normalizing and Annealing

The critical range of stainless steel is in the vicinity of 1530 degrees Fahr. As with any other air-hardening steel, normalizing is impossible. The range of hardening and that of normalizing are almost identical, hence the failure of the process. Strains incidental to forging and machining can be relieved by holding the steel at a temperature of about 1300 degrees Fahr. for a short time, allowing it to cool in the air.

In annealing for extreme softness, stainless steel is held at a

temperature of 1550-1600 degrees Fahr., for a period of time in proportion to the mass of steel, and then allowed to cool off in the furnace. As with any other steel, very slow heating and cooling through the critical range is recommended. Although steel an-nealed in this manner possesses the maximum degree of softness, it is not in a desirable condition for good machining. A very fine cut or a smooth finish with this degree of annealing is not possible, as the steel is so soft that it machines "gummy" and the tool in cutting drags and tears the material, leaving a rough, undesirable surface.

To soften stainless steel to a state in which it shows good machining properties, it should be held for several hours at a temperature of from 1350 to 1400 degrees Fahr., and allowed to cool either in the furnace or in the open air. As the critical point of the steel is never reached or exceeded by this method, it can readily be seen that the process is not one of annealing, but really one of high temperature drawing, in which the steel is drawn at a temperature below its critical point.

Stainless steel which has been annealed by heating to 1550 to 1600 degrees Fahr. will show a Brinell number of from 150 to 200, while that which has been softened by heating from 1350 to 1400 degrees Fahr., will show a Brinell number between 200 to 250.

Hardening

The proper hardening range for stainless steel is from 1750 to 1900 degrees Fahr., depending upon variations in composition and size. The steel being an air-hardening one, thin sections or intri-cate shapes which are likely to warp or break if quenched, can be hardened by air-cooling from the higher temperatures of the range, but the work will not be quite so hard as if it had been cooled in oil or water. The steel shows its maximum hardness when quenched in water or brine, but for all general purposes, quenching in oil at 1800 to 1850 degrees Fahr., will give the best results. The higher the quenching temperature, within reasonable limits, the better the general results will be in its resistance to stain. Although stainless steel hardens at a comparatively high temperature, its hardening must not be confused with that of high speed steel. It is quite difficult to burn high speed steel at a very high heat if all other

conditions are proper, while stainless steel can easily be burned and even ruined at temperatures necessary for the other steel.

Considrable care should be exercised in heating stainless steel for hardening, as it absorbs heat very slowly. An interesting experiment is to take a piece of carbon tool steel and one of stainless steel, both of the same size and shape, and place them in a furnace to heat to 1825 degrees Fahr., the hardening temperature of stainless steel. The carbon steel heats up readily and becomes uniformly colored, while the stainless steel remains a dark or dull red for a long period of time after the other steel has reached the required temperature. Thus it follows that stainless steel should be heated at least twice as long for hardening as ordinary tool steel. Properly hardened stainless steel shows a Brinell hardness number of from 550 to 600. The scleroscope does not give a good indication of hardness, as it is quite difficult to obtain values much in excess of 85 on carefully hardened specimens. Stainless steel hardens very deeply and possesses a fine, silky, hardened fracture, which resembles high speed steel, although not quite so dense.

HEAT RESISTANCE

Scaling and Properties at High Temperatures

Stainless steel commences to scale at a temperature of about 1500 degrees Fahr., or in the vicinity of its critical range. With ordinary steel as the temperature rises, the temper color film gradually develops into scale. Even at very low temperatures, the thickness of this scale increases with time. Stainless steel behaves quite differently up to a temperature near 1500 degrees Fahr., the glossed surface due to polishing and heat tinting remains permanent and the specimen neither gains nor loses appreciably in weight. Upon increasing the temperature, a thin film of tightly adhering scale is formed, but no oxidation of any extent is present until a temperature of from 1700 to 1800 degrees Fahr. is reached.

Stainless steel retains its strength with increasing temperatures to a remarkable extent, being exceeded in this important property only by high speed steel, which is considerably more brittle at the elevated temperatures. A table showing the comparative values of structural carbon steel and stainless steel when pulled at high temperatures is given in Table I.

Table I

Effect of High Temperatures Upon Tensile Properties

	Hardened Stainless Steel			Normalized Structural Steel		
Temp. of tests	Ten. Str. Lbs. sq. in.	Elong. % in 2"	R. A. %	Ten. Str. Lbs. sq. in.	Elong. % in 2"	R. A. %
575 F.	242,592	8.8	13.0	72,000	23.2	55.8
750 F.	227,360	4.0	6.6	55,448	37.2	68.5
930 F.	194,880	8.8	27.5	44,800	38.0	73.0
1100 F.	71,680	19.2	70.1	28,000	48.0	86.0
1300 F.	31,360	32.8	72.8	16,232	56.0	93.0

Tempering and Temper Colors

Stainless steel not only possesses the property of red hardness to a remarkable extent, but the permanence of its surface at the usual tempering heat is apt to cause confusion, if any attempt is made to compare it to the temper colors appearing on carbon steel at such temperatures. Temper colors appear on stainless steel at a considerably higher temperature than on carbon steel, in much the same degree as a higher heat is required to draw stainless steel to the same extent of softness. Thus a heat which will produce a similar degree of softness on stainless steel will show about the same temper color as that required for carbon steel. Temper colors as used in connection with stainless steel are not reliable. The use of a salt bath or tempering oven with pyrometer control is recommended for all drawing operations.

For those who desire to use or experiment with temper colors, Table II is offered, which gives the approximate temperature at which colors appear on both carbon and stainless steels. By refer-

Table II

Tempering Colors

Color	Appears on Carbon Steel		Appears on Stainless	
	Deg. Cent.	Deg. Fahr.	Deg. Cent.	Deg. Fahr.
Pale Straw	220	420	250	482
Dark Straw	230	446	300	572
Dark Straw-Brownish..	240	464	350	662
Brownish-Purple	260	500	400	752
Reddish-Purple	270	518	450	842
Full Purple	290	554	500	932
Blue Purple	300	572	550	1022
Dark Blue	310	590	600	1112
Greenish-Blue	320	608	650	1202
Steel Grey	340	644	700	1292
Brownish-Grey	360	680	750	1382

ence to the table, it can be noted at the higher temperatures it
requires almost double the heat necessary for carbon steel to give
the same color result on stainless steel.

The effect of tempering upon hardness, tensile properties, re-
sistance to stain, etc., will be covered later under the headings
"Tensile Properties" and "Corrosion."

Tensile Properties

In addition to its resistance to heat and corrosion brought
about by the combined properties of red hardness and surface sta-
bility, stainless steel also ranks high among steels noted for their
high tensile strength, being a close competitor to the well-known

Table III

Tensile Properties of Stainless Steel

	0.30% Carbon		13.00% Chromium			
	Oil quenched at 1825 deg. Fahr.		Drawn as indicated			
Drawn at	Yield P. Lbs. sq. in.	Ten. Str. Lbs. sq. in.	Elong. % in 2"	R. A. %	B. N. No.	Fracture
550	217,330	248,670	1.5	4.0	475	Flat
600	206,330	238,720	1.5	3.0	470	Flat
650	202,330	241,330	1.5	2.5	470	Flat
700	205,080	229,330	1.5	1.5	470	Flat
750	209,250	245,500	1.5	2.5	470	Flat
800	208,330	247,750	5.0	20.0	460	Flat
850	207,000	243,520	7.0	19.0	460	Flat
900	208,000	244,670	8.5	25.5	460	Flat
950	203,510	258,770	8.3	19.5	480	Flat
1000	195,510	250,270	6.6	15.9	460	Flat
1050	191,450	225,060	7.4	32.0	425	Flat
1100	170,560	197,180	10.2	32.7	375	Starry
1150	145,140	174,860	9.9	31.6	375	Starry
1200	131,670	159,280	11.7	37.9	335	Starry
1250	125,360	150,680	12.2	39.2	325	Starry
1300	121,150	146,800	12.4	40.5	315	Starry
1350	113,760	140,660	13.4	43.5	305	Starry
1400	103,900	130,970	14.4	45.8	285	Starry
1450	104,040	137,860	12.8	39.5	305	Cupped
1500	114,140	159,970	12.4	34.0	340	Starry
Ann'd	65,000	99,950	27.0	58.7	175	Starry

chrome-nickel and chrome-vanadium combinations. It is especially
valuable on account of the wide drawing temperature range at
which a 200,000 pounds per square inch breaking strength can be
obtained. When properly hardened, little difference is noted in
tensile strength of the steel whether it is tempered at 500 or 900
degrees Fahr.

Table III gives a list of approximate values obtained by drawing the hardened steel at various temperatures.

These figures are the average of results obtained in ten different compositions, three tests being made at each heat on each composition. It should be understood, however, that such a list of figures is only typical and is given with the purpose of serving as a guide. Better physical properties may be obtained, but at a sacrifice in stainlessness, by lowering the quenching temperature.

CORROSION

Although stainless steel is a steel of high tensile value and one which offers great resistance to heat oxidation and the softening effects which usually accompany high temperatures, its most remarkable feature is its surface stability or resistance to stain, corrosion and rust. The steel shows this exceptional property to a maximum degree only when in the hardened condition, and when a clean, smooth surface is exposed. Pitting, due to non-metallic inclusions or adhering scale, is very objectionable.

Weathering, which is the most common of all corrosive influences, has little or no effect upon the steel. Samples have been exposed to all types of weather, wet and dry, frost and snow, for many months and at the end of that time have been perfectly bright and unaffected in any way. Specimens placed in streams have retained their original brightness after months of exposure. Water containing a high percentage of dissolved oxygen has no appreciable effect upon the steel. The atmosphere of industrial cities has a superficial effect, but this is due essentially to the products of combustion, present in such localities. Oxides of sulphur are found in smoke and in the finely divided cinders which are precipitated from it. In connection with a moist atmosphere, such conditions offer quite a severe test to the stain resistance of the steel. When free from defects, the material is little affected by sea water. The sea water or brine solution test, however, is an excellent one for testing the perfection or degree of resistance.

It is a well known fact, where two dissimilar metals are placed in contact in an electrolyte, a galvanic action is set up. This condition is very favorable to corrosion. Stainless steel is no exception to this rule. When it is used in a solution in connection

with bearing metals, such as copper, bronze and brass, considerable tarnishing and pitting of the surface is noted.

There is no doubt that stainless steel has made its reputation in the cutlery field. It is in this application, one of practical service, that it has clearly demonstrated its superiority over any other material heretofore offered. Millions of stainless steel knives in use today have permanently established its value for this purpose. Fruit and vegetable acids, such as are present in the orange, lemon, apple, tomato, etc., show no effect whatever. Pickling vinegar offers a slight attack, due to the presence of hydrochloric acid formed during the reaction of the acetic acid upon the sodium chloride or salt usually found in pickling solutions. The steel offers complete resistance to the effects of lye or ammonia. Thus it can readily be seen that the resistance of the steel to the above common corrosive agents, has made stainless steel an exceptionally efficient material for all kinds of table cutlery and culinary utensils.

The usual method of testing the steel for stain resistance is to place a drop of vinegar and a drop of 33 per cent nitric acid upon the clean, polished surface. Any mineral or vegetable oil present may be removed by the successive application of benzine and ether. The vinegar is allowed to dry on the test specimen so that the acetic acid contained in it may pass gradually through the various degrees of concentration at room temperature. The nitric acid may remain on the sample any stated time from 2 to 10 minutes, but the period of time must always be the same so as to make the results comparative. The efficiency in regards to stainability is measured by the degree of stain resulting from the application of these acids. Other methods of testing are accomplished by the use of mixed solutions of the three common organic fruit acids, tartaric, citric and acetic, and also by copper sulphate solutions. Although valuable comparisons can be made by the use of these latter reagents, they are more or less impractical and serve only as laboratory tests.

Mention has been made of the fact that the steel shows its highest resistance to stain when in the hardened, or some modification of the hardened state. This rule applies to all cases, whether the hardness be due to a high quenching temperature or the result of a low tempering heat. Within reasonable limits, in which com-

position plays an important part, the harder the steel, the more resistant the surface is to stain.

Several summaries have been worked out (Tables IV and V), showing the increase in stainability due to quenching at rising temperatures, also the decrease which takes place when high tempering heats are used.

Table IV
Resistance to Stain When Hardened at Various Temperatures
Samples 1½ inches round by 1 inch thick

Temperature degrees Fahr.	Brinell	Scler.	10% *CuSO₄	33½% †Nitric	5% ‡Acetic
O. Q. 1500	340	56	50	90	50
O. Q. 1550	360	60	75	90	50
O. Q. 1600	440	70	85	90	50
O. Q. 1650	470	75	90	90	85
O. Q. 1700	485	78	90	90	85
O. Q. 1750	525	80	95	95	85
O. Q. 1800	550	83	95	95	90
O. Q. 1850	600	86	95	100	95
O. Q. 1900	615	87	100	100	95
O. Q. 1950	615	87	100	100	95
O. Q. 2000	615	87	100	100	100
O. Q. 2050	560	84	100	100	100
O. Q. 2100	560	84	100	100	100

The above figures on corrosion have been estimated by the appearance of the stains resulting from the application of the various reagents. They denote approximately the comparative efficiency in per cent. *CuSO₄ reacted six minutes. †Nitric reacted two minutes. ‡Acetic dried on.

Table V
Effect of Tempering on Resistance to Stain
Samples 1½ inches round by 1 inch thick   Oil quenched 1825° F.
Drawn as indicated

Drawn at	Brinell	Scler.	*CuSO₄	†Nitric	‡Acetic
Not drawn	600	86	100	100	100
400° F.	590	86	100	100	100
500	600	86	100	100	100
600	590	85	100	100	100
700	590	85	100	100	100
800	590	85	100	100	100
900	550	83	95	100	95
950	500	78	95	100	90
1000	475	76	95	100	90
1050	450	73	90	100	90
1100	400	67	85	100	90
1150	375	64	80	100	90
1200	350	61	70	95	85
1250	325	57	65	95	85
1300	315	52	60	95	85
1400	275	48	50	95	85
1500	325	57	25	90	80
Annld.	185	32	25	90	75

The above figures on corrosion have been estimated by the appearance of the stains resulting from the application of the various reagents. They denote approximately the comparative efficiency in per cent. *CuSO₄ reacted six minutes. †Nitric reacted two minutes. ‡Acetic dried on.

In the foregoing discussion, mention has been made only of the application of stainless steel to common household articles and of its resistance to tarnishing agents met with in every day life. However, its use is not limited to this narrow field. As a matter of fact it has a very wide field of application, to which it readily adapts itself, as shown by its behavior with the various corrosive reagents.

Resistance to Acids

Aqua Regia—Stainless steel offers very little resistance to this combination of acids, regardless of whether the steel is hardened or annealed.

Acetic Acid—Glacial acetic acid has no effect. Diluted to various strengths it attacks slightly. It is a remarkable fact that vinegar, which contains 5 per cent acetic acid, has little or no effect upon properly hardened and polished stainless steel. Acetic anhydride reacts readily upon the steel, as does also monochloracetic acid. Trichlor-acetic acid most violently attacks the steel in any condition.

Boric Acid—The steel is totally unaffected by this acid in any degree of concentration.

Citric Acid—The steel is corroded in proportion to the strength of the acid. Lemon juice containing about 6 per cent citric acid has no effect.

Formic Acid—The steel is attacked to a limited degree.

Hydrochloric Acid—Stainless steel offers little resistance to this acid.

Lactic Acid—Corrodes to a considerable degree. Sour milk, although high in lactic acid content, does not attack the steel.

Oleic and Stearic Acids—Neither acids show any appreciable effect upon the steel.

Phosphoric Acid—A saturated solution has no effect. In various degrees of concentration, a slight general attack takes place.

Nitric Acid—Practically no effect upon the steel. Dilute solutions very slightly attack some types of the low carbon variety.

Sulphuric Acid—Readily attacks in any degree of concentration.

Sulphurous Acid—Very similar in its reactions to sulphuric acid.

Tannic Acid—Does not offer any attack.

Resistance to Various Solutions and Gases

Acetone—Slightly attacks steel.

Alum—Strong solutions readily react upon the steel.

Alcohol—The hardened steel is not appreciably attacked by ethyl alcohol or any liquors containing it in solution.

Alkalies—Caustic alkalies have no effect whatever upon the steel. Solutions of ammonia behave in a similar way.

Ammonium Chloride—Very marked corrosion.

Ammonium Sulphate—Steel is readily attacked.

Blood—No corrosive action at all from the effect of beef, hog and sheep blood.

Benzol—Totally unaffects the steel.

Calcium Chloride—Does not attack the steel in a saturated solution but dilute solutions have a slight effect.

Carbon Tetrachloride—Like the majority of corrosive agents, the pure liquid has no effect but dilute alcoholic solutions readily attack the steel.

Copper Chloride—Readily attacks the steel.

Copper Sulphate—In a neutral solution, this salt does not appreciably affect the hardened steel.

Chlorine—Either dry or moist chlorine gas readily attacks the steel.

Dry Battery Compound—(A mixture of zinc and ammonium chloride with manganese dioxide.) Very marked corrosion takes place.

Ferric Chloride—Readily attacks.

Iodine—Corrodes but to a limited degree.

Lime—No effect whatever upon the steel.

Ink—Stainless steel has been tested with various makes and colors of ink. Little effect has been noted, although in some cases the steel was stained slightly.

Lysol—Has no effect.

Mercuric Chloride—A marked corrosion takes place when strong solutions are used. Very dilute solutions, such as are used for surgical antiseptics, have little effect.

Menthol—Strong alcoholic solutions stain the steel in proportion to the degree of concentration.

Magnesium Carbonate—A thick paste of this material was allowed to dry on the steel. No effect was noted.

Novocaine—To note its adaptability for hypodermic needles, the steel was immersed in a 1 per cent solution of this substance for seven days. No appreciable effect was disclosed.

Mercury—No attack whatever.

Oils—Light or heavy lubricating oils, cylinder and paraffin oils have no effect.

Potassium Cyanide—No effect.

Potassium Ferrocyanide—Readily attacks the steel.

Potassium Oxalate—No effect.

Quinine Sulphate and Bisulphate—Steel is noticeably pitted.

Sodium Chloride—Pitted locally by saturated solution.

Sodium Salicylate—No noticeable effect.

Sodium Sulphate—Strong solutions of this salt readily attack the steel.

Soft Soap—Has no effect upon the steel.

Sugar—Totally unaffected by any strength of solution.

Steam—No corrosion offered unless considerable amounts of some salt or acid is in solution in the water.

Silver Bromide—No attack offered by this salt.

Sulphur Chloride—In the presence of water or moisture, the steel is readily attacked by this corrosive chemical.

Tannin—Practically no effect.

Thymol—Slightly stained by strong solutions.

GENERAL PROPERTIES

Brazing and Welding

Stainless steel can be soldered, but due to certain difficulties presented, the process of brazing is to be preferred. It is possible to successfully braze the steel if proper precautions are taken as to composition of brazing material, kind of flux and the temperature of the work. A brass brazing alloy, composed of equal parts of copper and zinc, is recommended. The working temperature is considerably above that customary for such work, being in the vicinity of 1600 degrees Fahr., which is well above the melting point of the brazing alloy. A paste which has given successful results is made by mixing four parts by weight of borax to one of ferric-chloride in hydrochloric acid. This solution is used to

form a thin paste with zinc-chloride. It is essential that the sur-
face to be brazed be free from dirt, scale and grease.

Stainless steel can be successfully welded by the electrical con-
tact or fusion method. Both of these processes permit of its union
to carbon steel. It must be understood, however, that in electric
welding, the temperature of the metal at the point of contact is
raised very high and that the resulting structure formed will be
hard and coarse, with a tendency toward brittleness. Where at all
possible, welded work should be softened before further fabrication
or treatment.

It is possible to weld stainless steel by means of the acetylene
torch but results are not entirely satisfactory.

Coefficient of Expansion

The degree of expansibility of stainless steel is of considerable
importance when used in connection with internal combustion
engine valves, steam fittings, etc. Although only slightly less in
degree of expansion than ordinary steel, there is sufficient differ-
ence to be of considerable advantage. Table VI is taken from
"Scientific Paper No. 426," U. S. Bureau of Standards.

Table VI

Coefficients of Expansion of Stainless Steel
Average Coefficients of Expansion

Temperature Range	Hardened	Annealed
20 to 100 degrees Cent.	.0000099	.0000103
20 to 200 degrees Cent.	.0000098	.0000107
200 to 400 degrees Cent.	.0000099	.0000123
400 to 600 degrees Cent.	.0000138	.0000133
600 to 800 degrees Cent.	.0000134	.0000136
20 to 600 degrees Cent.	.0000112	.0000121

Cold Drawing and Cold Rolling

Both cold drawing and cold rolling are possible. In drawing,
however, frequent annealings are necessary and very few passes
can be accomplished between annealings. In other words, the steel
is quite difficult to cold draw when it contains the standard carbon
content. With carbon under 0.15 per cent it can readily be drawn.
It is practical to cold-work stainless steel into almost any shape
possible with carbon steel, including sheets, strips, bevels, turbine

blading, etc., but a carefully prearranged routine must be followed in order to obtain good results.

It might again be stated that distorted surfaces are likely to rust. In the cold drawn condition, stainless steel is not sufficiently immune from stain and rust to permit of its use in such a state, due to the strains and distortions set up during the process. Such strains are not confined to the surface whereby they can be ground off, but are inherent in the steel and must be removed by heat treatment. All cold worked material made of stainless steel should be annealed and hardened like the ordinary hot rolled steel, and then ground and polished in its final condition, if the full advantage of its stain-resisting properties are to be obtained.

Cutting Properties

No claim is made for stainless steel as a suitable steel for cutting metals. Its cutting field is limited to table cutlery, pocket knives, surgical instruments, meat cutting blades, leather knives, etc. For these purposes it serves admirably. There has been just a little contention in the past as to the extent stainless steel is capable of taking and retaining a keen cutting edge. The fact must be taken into consideration that the best knife is the one in which hardness and resiliency are about equally proportioned. This condition can be obtained in stainless steel. That the cutting qualities of stainless steel when properly hardened compare very favorably with the best grades of carbon steel knives and are far superior to the cheaper grades, is shown by the following comparisons made of the Brinell hardness of the various types.

Table VII

Comparative Hardness of Stainless and Carbon Steel Knives

Type of Knife	Brinell Hardness Number
Good Shear Steel Carver	505 to 525
Good Shear Steel Table Blade	510 to 530
Common Steel Carver	510 to 525
Common Steel Blade	510 to 525
Best Cast Steel Pocket Blade	560 to 580
Best Cast Steel Razor	625 to 640
Stainless Carvers	500 to 520
Stainless Steel Table Blades	500 to 550
Stainless Pocket Blades	550 to 600

In the past, attention has been called to knives made of stainless steel which were not considered hard enough for table use. The fault with these, however, is not usually in the steel but in the hardening. They have not been properly hardened. For years, makers of cutlery have been accustomed to the working of carbon steel, which hardens at a red heat, about 1400 degrees Fahr. A heat of approximately a lemon color (about 1825 degrees Fahr.) is necessary to properly harden stainless steel. It can readily be seen that the tendency is towards quenching at too low a heat. In exceptional cases, however, the other extreme is sometimes reached. Knives have been examined which were soft yet brittle on the tip or point of the blade. These blades had no doubt been considerably overheated and burnt by heating the point downward in a forge fire. This condition is easily distinguished by the coarse crystalline appearance of the fracture. Many other factors, such as decarburization of the cutting edge, improper grinding, and lack of uniform heating and quenching, have in the past given faulty results which have been wrongly attributed to the lack of hardening properties in the steel. In justice to the many high class concerns today engaged in producing stainless steel cutlery, it can be said that most of these discrepancies have been overcome and very satisfactory knives can now be obtained.

Ordinary steel knives stain and discolor readily, which necessitates frequent scouring or cleaning with an abrasive. This daily operation has a tendency to keep the cutting edge sharp. Stainless steel does not require scouring and thus it sacrifices some cutting properties to carbon steel by reason of this virtue, but stainless steel knives may be sharpened on a steel without detriment when necessary.

Electrical Conductivity and Resistivity

The electrical specific resistance in the soft condition is 50 to 55 microhms per centimeter. In the hardened and tempered condition its resistance is increased to 65 to 70 microhms per centimeter. For transmission purposes, it may be compared to pure iron which has a resistance of only $\frac{1}{6}$ that of stainless steel. The resistance of copper is $\frac{1}{8}$ that of pure iron, so by comparison the resistance of the steel is about 50 times as great as that of copper.

The resistance of the steel is only about half that of Nichrome.

A comparative table of the approximate electrical resistance of three common substances follows:

Material	Microhms per centimeter
Copper	1
Pure Iron	8
Stainless Steel	50
Nichrome	100

Etching

Stainless steel shows a remarkable resistance to the effect of nitric acid whether cold or boiling and in any degree of concentration. It is readily attacked by both hydrochloric and sulphuric but neither of these acids alone serve as a good etching medium. The following mixtures and solutions have been found to give satisfactory results:

1. Saturated solution of ferric-chloride in hydrochloride acid to which a little nitric acid has been added. Use full strength.

2. Aqua Regia (3 HCl, 1 HNO_3). The mixture of these two acids should be allowed to stand for 24 hours before using. Use full strength.

3. For light etching. A saturated solution of copper-sulphate in hydrochloric acid.

4. For light etching.

Hydrochloric acid	100	parts
Water	100	parts
Mercurous Nitrate	6.5	parts
Heat to effect complete solution but use cold		

Several satisfactory methods of applying the etching reagents have been worked out. In each case an engraved steel die is used to make an impression through a paraffin coated paper which is used with a varnish preparation to protect the steel in the neighborhood of the etching from the acid. No difficulty is obtained in getting very satisfactory results.

Grinding

Aside from proper hardening, by far the most important process which influences stain-resistance, is that of grinding. It should be realized at the start that stainless steel is more difficult to grind than ordinary carbon steel. As has been mentioned several times before, stainless steel dissipates heat very slowly, so great care

should be exercised in grinding the hardened steel so that heat checks and grinder's scorch are not produced. Grinder's scorch is a yellowish-brown discoloration, due to harsh or unskilled grinding. Frictional heat is generated in local patches on the surface of the work and the resulting discoloration has every appearance of stain. This apparent stain is in reality a temper color but actual staining is quite likely to occur on surfaces where it is present, due to the distortion set up. Wet grinding is to be preferred with finishing dry, which latter must be done lightly. The grinding must be deep and thorough, every trace of forging scale and surface decarburization must be removed. Any remaining oxides or pits serve as seats for corrosion and an electrolytic action is set up which readily spreads over the surface of the material.

For finishing, the polish must be ground on. A burnished or flowed on polish is not permissible with this steel, as it leaves the surface in a state of distortion, which is favorable to staining. Then again, burnishing does not permit of the removal of an undesirable surface, although a higher polish is possible which deceives one into believing that all the blemishes have been removed.

In the past it has been the belief of some not thoroughly familiar with the properties of this steel, that the surface stability of stainless steel is due entirely to the degree of excellency to which the surface had been polished. This is a mistaken idea. The stain and rust resisting property of this material is inherent in the steel, being the result of composition combined with heat treatment and is not due to any surface effect. Of course, it must be admitted that a smooth, highly polished surface is to be desired to a rough ground one. With stainless steel, the same as with any other steel, the higher the polish the more satisfactory the results.

Machine Properties

Stainless steel can be annealed very soft. In this condition it will show a Brinell value of about 150, but its machining properties will be poor. It is generally agreed that a very soft steel cuts "gummy," pulls and drags, making it undesirable for any purpose requiring a smooth, clean surface. The same is true of stainless steel.

Good machining properties in this steel cover a range of hardness of from 200 to 300 Brinell. Even at the high point of this

range the material cuts well, although a little crisp. For any purpose where sharp angles are desired or a machined surface free from roughness and unusual distortions, the harder material is recommended. Still another feature of the harder condition of the steel, which is the result of hardening with subsequent tempering, is the fact that in addition to its machining properties, it still retains most of the stain-resisting qualities which it possessed in the hardened condition.

As previously stated, stainless steel conducts heat very slowly, and its expansion upon heating is less than carbon steel. These two characteristic properties when acting in conjunction, make drilling difficult. Frictional heat is generated, which is slowly dissipated, causing the drill to unduly heat up and gall, unless precaution in the way of a cooling and lubricating medium is used.

Magnetic Properties

Fairly good magnets can be made from stainless steel. It is a splendid material for use where resistance to corrosion is required. In the soft state, it has the same degree of permeability as that of a 0.90 per cent carbon steel in the normalized condition. Its best magnetic properties are brought out when it is hardened. Aside from its stain-resisting advantages, stainless steel does not compare favorably with the usual chrome-and-tungsten-magnet steels.

Melting Point

The melting point of stainless steel is higher than that of high speed steel. From observations taken during the melting of the steel and the pouring and solidification of it into ingots, the melting point has been found to be in the vicinity of 2750 degrees Fahr.

Microstructure

Annealed stainless steel shows a uniformily sorbitic structure, although sometimes crystals of a complex chromi-ferrous ferrite segregate themselves. There has been considerable discussion and controversy regarding the micro-structure of hardened stainless steel. Some authorities claim that no free carbides exist, but the writer is of the opinion that it all depends upon the hardening

temperature used to effect the solution of the carbides. Hardened at 1700 degrees Fahr. the steel will show a martensitic structure with numerous globules of double carbides of iron and chromium present. When quenched in the vicinity of 1950 degrees Fahr. no free carbides are present, the whole structure being of a purely martensitic nature. When the temperature of quenching is raised still higher, an austenitic structure results, and further complications are presented. An interesting and unusual phenomenon is associated with this particular form of austenite. Although in the normal state it is comparatively soft, drawing has the effect of reducing it back to martensite, at the same time producing the characteristic hardness of the latter.

Modulus of Elasticity

Experiments have shown that the modulus of elasticity of stainless steel is in the vicinity of 30,000,000 pounds per square inch.

Rusting of Commercial Bars

Stainless steel is usually shipped out to the trade in annealed, hot rolled bars. In this state the tendency toward rusting is considerable, due to surface conditions. The steel shows minimum resistance when in the soft annealed condition, which, in connection with the adhering film of oxidation, permits of a ready attack from a moist atmosphere. Incomplete removal of formations incidental to pickling, also leaves the surface in a state very favorable to electrolysis and oxidation. For the reason stated, commercial bars of stainless steel are even more likely to rust than ordinary steel, unless special precautions are taken to prevent it.

Thermal Conductivity

The thermal conductivity of stainless steel is poor, being only about one-third that of iron.

Specific Gravity

The specific gravity of stainless steel is 7.75, being less than

that of carbon steel. A comparison between it and the most common tool steels is as follows:

Steel	Specific Gravity
High Speed 18 per cent Tungsten....................	8.75
Carbon Steel 1.0 per cent Carbon....................	7.83
Stainless 0.30 per cent Carbon 13.00 per cent Chromium..	7.75

STAINLESS IRON

The field of general usefulness of stainless steel has been greatly increased since the introduction of the new and modified form known as "stainless iron." This material is a low carbon type of the standard 13.00 per cent chromium steel. The composition is approximately as follows:

	Per Cent
Carbon	0.08 to 0.13
Silicon	under 0.30
Manganese	0.25 to 0.35
Sulphur	under 0.030
Phosphorus	under 0.030
Chromium	11.50 to 15.00

Stainless iron forges very similar to a 0.40 per cent carbon steel and can be drop-forged without any difficulty. Its best working range is 1600 to 1900 degrees Fahr. Overheating has a tendency to produce a crystalline structure. Like the higher carbon variety, it is necessary to soak at the required forging temperature for good results. Stainless iron does not air-harden to any extent unless it is cooled very quickly from the forged condition. Working strains, however, should be removed by heating to a dull red and allowing to cool off slowly.

Stainless iron responds readily to heat-treatment. Excellent results as regards elasticity and toughness can be obtained by applying special treatment. Impact values in excess of 50-foot pounds, in connection with very satisfactory tensile properties, are possible.

APPLICATIONS AND POSSIBILITIES

Stainless steel was originally intended for cutlery and for that purpose has proven a great success. Among other purposes for

which it has proven very efficient may be included surgical instruments, turbine blading, pump rods and pistons, and high grade hardware.

There is yet a wide field of possibilities open, although its use may always be more or less limited to high grade articles on account of its comparatively high cost. For marine and mining machinery parts, it should prove quite a valuable material. Makers of scientific apparatus will no doubt find it well adapted for certain metallic parts in their instruments. The culinary field, with its wide variety of associated articles, offers tremendous possibilities.

In conclusion, it might be said that the application of stainless steel and its modified forms is yet in its infancy. It is possible that the future may revolutionize manufacturing costs to such an extent that the steel will be available in any quantity.

SPHEROIDIZED CEMENTITE IN HYPOEUTECTOID STEEL

By R. S. MacPherran and J. F. Harper

Abstract

In this paper are given the results of the authors' experience in a method of heat treating large forgings.

The question of uniformity of tests, as well as the increased ductility of the same, were the reasons for the investigations described. The results obtained by the spheroidization of the cementite of the pearlitic constituent seem to warrant the treatments given.

This treatment applied to cast steel results in a corresponding improvement of physical properties.

THIS INVESTIGATION was conducted by the Allis-Chalmers Manufacturing Company, in order to show the beneficial effects of a "loneal"* upon the physical as well as the structural characteristics of certain low and medium carbon steels. The use of a loneal is not generally applied to forgings, and where it is, the authors do not believe that the reasons for the better results are generally understood.

The object of this investigation was to increase the ductility of forgings, especially the ductility, transversely or radially to the direction of forging. The method as developed was by spheroidizing the cementite of the pearlitic constituent of the hypoeutectoid steels.

Spheroidizing the cementite in hypereutectoid steels, especially the tool steels, has been practiced for some time to increase their

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*Loneal—Heating below the "critical temperature," followed by any rate of cooling. (Proposed definition A. S. S. T.)

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machineability and the toughness. The earliest use of this property of cementite is probably the Damascus blades, the famous swords of mediæval times.

There are many references in the literature to this class of spheroidizing, but there are only meager references to spheroidizing in a hypoeutectoid steel. Howe,[1] Howe and Levy[2] refer to the effects of divorce annealing, which is the spheroidizing or the coalescing of the cementite contained in the pearlitic constituent of hypoeutectoid steels. They show three steels in the hypoeutectoid class, namely, 0.03, 0.21, 0.59 carbon. In all cases shown there was a decrease in the tensile strength and the yield point; and a decrease in the elongation and the contraction, with the exception of a 0.03 carbon steel. They further state, "we must not overlook the damage which divorcing does by assembling the divorced cementite into harmful, large, brittle atolls. The breaking up of these cementite islands might well cut gashes hard to heal and thus start rupture."

Whiteley,[3] using the term globular pearlite, designating the type of pearlite which is in a spheroidal shape and not lamellar, states that "it is necessary for carbide nuclei to be present to inoculate the solid solution in order for this globular pearlite to form." He further states "that the carbide constituent of pearlite is not at once dissolved completely at the Ac_1 point. With coarse grained hypoeutectoid steels, heating for more than fifteen minutes was needed at 760 degrees Cent. (1364 degrees Fahr.), which was more than 40 degrees Cent. (104 degrees Fahr.) above the Ac_1 point, to effect a complete solution, and much longer periods were necessary at lower temperatures."

He found the persistence of the nuclei in the solid solution even after heating at 800 degrees Cent. (1472 degrees Fahr.) for forty-five minutes. He suggests "that, in hypoeutectoid steels, at any rate, the formation of lamellar pearlite only during slow cooling indicates the entire absence of carbide nuclei from the solid solution." The globular pearlite is formed "as the temperature falls below Ac_1, the rate of formation is slow at first and then increases rapidly until Ar_1, at which lamellar pearlite can grow, is reached."

[1]"The Metallography of Steel and Cast Iron," by H. M. Howe.
[2]"On Divorce Annealing," by Howe and Levy. Proceedings Cleveland Institute Engineers, 1913, 1914.
[3]"The Formation of Globular Pearlite," by J. H. Whiteley, in Journal of the Iron and Steel Institute, 1922. No. 1 Vol. CV.

Ihsen[4] shows an illustration of a spheroidal 0.34 carbon cast steel, although the main part of his article is written about a 1.00 carbon or eutectoid cast steel. His results show an increase in the ductility, the increase in the reduction of area being 13 to 20 per cent in the spheroidized steels with a slight decrease in the ultimate tensile strength. "The interpretation of these physical test results reveals a decided advantage from the standpoint of ductility and shock resisting properties when the steel is in the spheroidized condition. A steel heat treated to obtain this structure should be more resistant to impact or shock than one in the pearlite condition." He further states, "A long time anneal at a temperature just below the thermal critical range is not necessary to obtain the spheroidized structure, provided that the material has received the proper preliminary heat treatment. Before the spheroidizing treatment, the material should be heated above the Ac_{cm} thermal critical range and cooled as rapidly as possible, then reheated to a temperature just above the lower critical range and again cooled as rapidly as possible.

After the proper preliminary treatment, only one or two hours drawing at a temperature just under the lower thermal critical was required to completely spheroidize the cementite.

Guillet and Portevin[5] speak of spheroidized cementite "as the small rounded grains of granular pearlite, formed by the coalescing of pearlite cementite as irregular plates in the ferrite. This structure is found more particularly in steels which have been subjected to prolonged annealing, which permits the pearlite and proeutectoid cementite to merge together. Granular pearlite is a form of pearlite which results from the coalescence of the cementite of lamellar pearlite either during the formation of the pearlite or during subsequent heating in the ferrite cementite area at as high a temperature as possible but below 700 degrees Cent. (1292 degrees Fahr.)."

"The conversion of lamellar to granular pearlite will be preceded," according to Benedicts,[6] "by a condition where the cementite will exist as chains or minute globules. Pearlite being formed after the other constituents, will constitute the ground

[4]"The Spheroidizing of Cementite in Steels," by H. C. Ihsen, *Forging and Heat Treating,* July, 1922.

[5]"Metallography and Micrograph," by Guillet and Portevin.

[6]"A New Form of Pearlite," by Dr. C. Benedichs, "Metalurgie," 1909, p. 569.

mass and its form and outline will be dependent on the other constituents.''

Honda and Saito[7] found the following:

(1) ''If a quenched specimen is heated to below the Ac_1 point pearlite cementite spheroidizes.

(2) ''If a hypereutectoid steel be heated above the Ac_1 point but below the solubility line, and quenched, the spheroidization of a portion of the super-eutectoid cementite takes place.

(3) ''If a lamellar pearlite steel be heated to just the Ac_1 point or a little above this point, for a certain interval of time, spheroidization takes place.

(4) ''Granular pearlite spheroidizes by being heated below the Ac_1 point for a sufficiently long interval of time.

(5) ''If the Ac_1 point is not reached, the spheroidization of lamellar cementite can never proceed. If the maximum temperature exceeds a certain limit above the Ac_1 point and is then cooled, cementite appears as a lamellar pearlite.

(6) ''The temperature interval of spheroidization in low carbon steels is very small, extending only to about 20 degrees Cent. (68 degrees Fahr.); it increases rapidly with the content of carbon. In very high carbon steels the interval amounts to about 100 degrees Cent. (212 degrees Fahr.).''

Ishewsky[8] shows a 0.83 per cent carbon steel in which the tensile strength drops from 109,000 pounds per square inch, to 76,500 pounds per square inch when it is put in the spheroidal state, and the elongation increases from 11.8 per cent to 19.75 per cent.

Hoyt[9] states, ''that granular pearlite is formed by reheating quenched steel to a temperature just below 700 degrees Cent. (1292 degrees Fahr.). And that the cementite particles grow by coalescence until they become visible under the microscope. This form of steel corresponds to the softest, weakest and most ductile state which can be assumed at normal temperatures. Granular pearlite is considered to be structurally stable and it represents the condition that all steels tend to assume at temperatures below the transformation point.''

[7]''On the Formation of Spheroidal Cementite,'' by Notalia Honda adn Seizo Saito.
[8]Ishewsky, International Journal of Metallurgy, 1914, Vol. 6, p. 199.
[9]''Metallography,'' by Hoyt.

It has been pointed out by Hanemann and Marve,[10] reviewing previous work, that granular pearlite can form in three other ways besides the one just described. (1) By very slow cooling passed the Ar_1 point. (2) By repeatedly heating and cooling through Ac_1 and Ar_1. (3) By long annealing of lamellar pearlite at temperatures just below Ac_1."

It is well known that the pearlite in low carbon tin plate tends to spheroidize.

From the above extracts there appear to be many views on the mechanism of spheroidizing which are more or less in agreement with each other. The authors have found that the size and shape of the pearlite grain is not materially affected by the spheroidizing treatment, and, therefore, to obtain maximum physical results the lamellar pearlite grain should be as small as possible and its relation to the ferrite grains as uniform as possible. The lamellar pearlite grain can be considered to consist of eutectoid composition. The rate of formation, of the alloying elements or impurities may, however, cause the composition to be slightly greater or less than that given as the true eutectoid composition. It is undoubtedly true that even within an individual lamellar pearlite grain the concentration may vary. It is, therefore, possible for the Ac_1 and Ar_1 point to vary for the pearlite constituent of various grains within the steel from the Ac_1 and Ar_1 of the steel considered as a whole.

The authors, therefore, agree with Honda and Saito in that if the Ac_1 point is not reached, spheroidization of lamellar cementite can never proceed, but further believe that this Ac_1 point need not necessarily be the Ac_1 point for the steel as a whole.

The value, indeed, of the loneal in low carbon forgings is largely due to the fact that the critical temperature (Ac_1) of the lamellar pearlite grain is lower than the Ac_1 of the steel as a whole, and that as above stated the interior of the grain only is affected.

Due to the variation in the concentration of the cementite within the pearlite grain, it is possible for areas of the cementite to be eaten away and held in the ferrite and the remainder of the cementite to coalesce by the surface tension action.

In large masses such as those on which the authors obtained their results, it is impossible to get complete lamellar pearlite

[10]Haneman and Marve, *Stahl and Eisen*, 1913, Vol. p. 1359.

throughout, and undoubtedly certain areas are granular pearlite. Certain pearlite areas may contain sorbite, such as obtained by quenching. Heating these types of pearlite below Ac_1 point causes coalescing and thus, according to Honda and Saito, the formation of spheroidal cementite.

In certain areas of pearlite, the cementite may be of sufficient concentration to be in excess and so held in the ferrite lamellae. Heating above the Ac_1 point and quenching causes the excess cementite to be centers for the formation of globular cementite.

It would appear from these experiments that the maximum ductility is obtained by the following procedure: A grain refining treatment is used to secure the best dispersed pearlite and ferrite areas of the smallest size. This usually consists of heating to above the Ac_3 point. Depending on the forging or casting conditions, this treatment may be preceded by a normalizing treatment. The spheroidizing is then accomplished by moderately long heating (five to eight hours) at or slightly below the Ac_1 point for the steel as a whole and cooling in air.

PHOTOMICROGRAPHS

The micrographs in this paper were taken with a Leitz microscope and are all at 1000 diameters magnification. A 4 millimeter apochromatic objective was used with a No. 3 projection eyepiece and a camera bellows extension of 51.5 centimeters. The specimens were etched with a 5 per cent solution of picric acid in alcohol.

Photomicrograph, Fig. 1 shows the structure of a piece of tin plate. The tin coating has been carefully polished off, leaving the steel surface. It will be noticed that even the small amount of pearlite which is present in this low carbon steel has been spheroidized in the process of manufacture.

Photomicrographs in Series I (Figs. 2, 3, 4) are of a forging $8\frac{1}{8}$ inches in diameter, by 10 feet 5 7/16 inches long, which was forged from an 18-inch ingot. Figs. 2 and 3 were taken after the forging had been annealed at 1465 degrees Fahr., and held at this temperature for five hours. It shows the characteristic lamellar pearlite of an annealed steel, but the physical properties show low ductility.

Magnification 1000 X

Fig. 1—Section of Tin Plate, Tinned Surface Removed by Grinding, leaving Steel Sheet.

Fig. 2—Series I
Magnification 1000 X
Steel Forging Y7465 B

Analysis		Longitudinal Test	
Carbon	.47		
Manganese	.75	Yield	51,700
Sulphur	.041	Ultimate	104,500
Phosphorus	.036	Per Cent Elongation	18.
Silicon	.240	Per Cent Reduction	28.

Treatment 1465 Degrees Fahr. Held 5 Hrs. Cooled in Furnace.
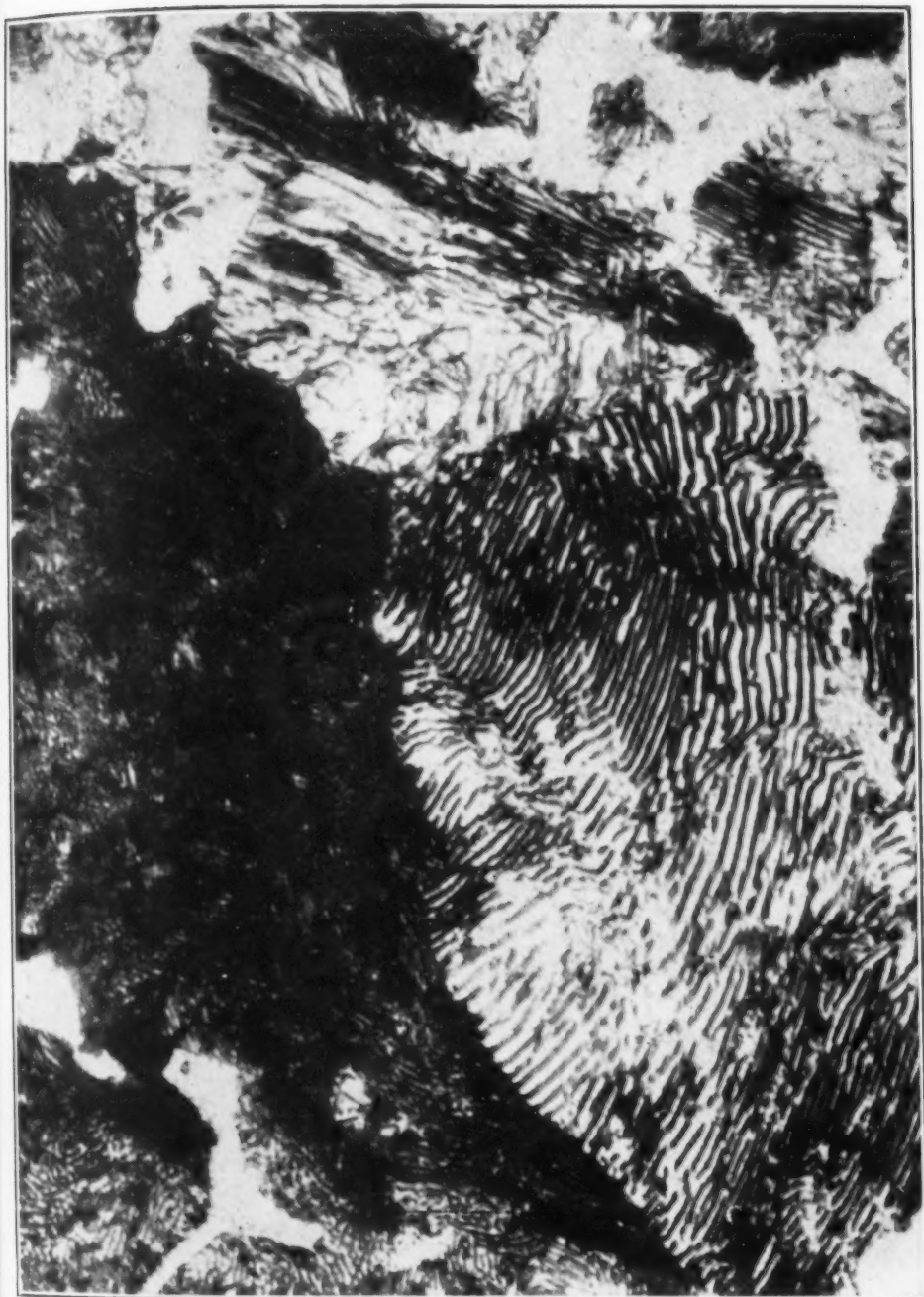
Fig. 3—Series I

Magnification 1000 X

Steel Forging Y7465 B

Additional View of Same Section as Shown in Fig. 2.
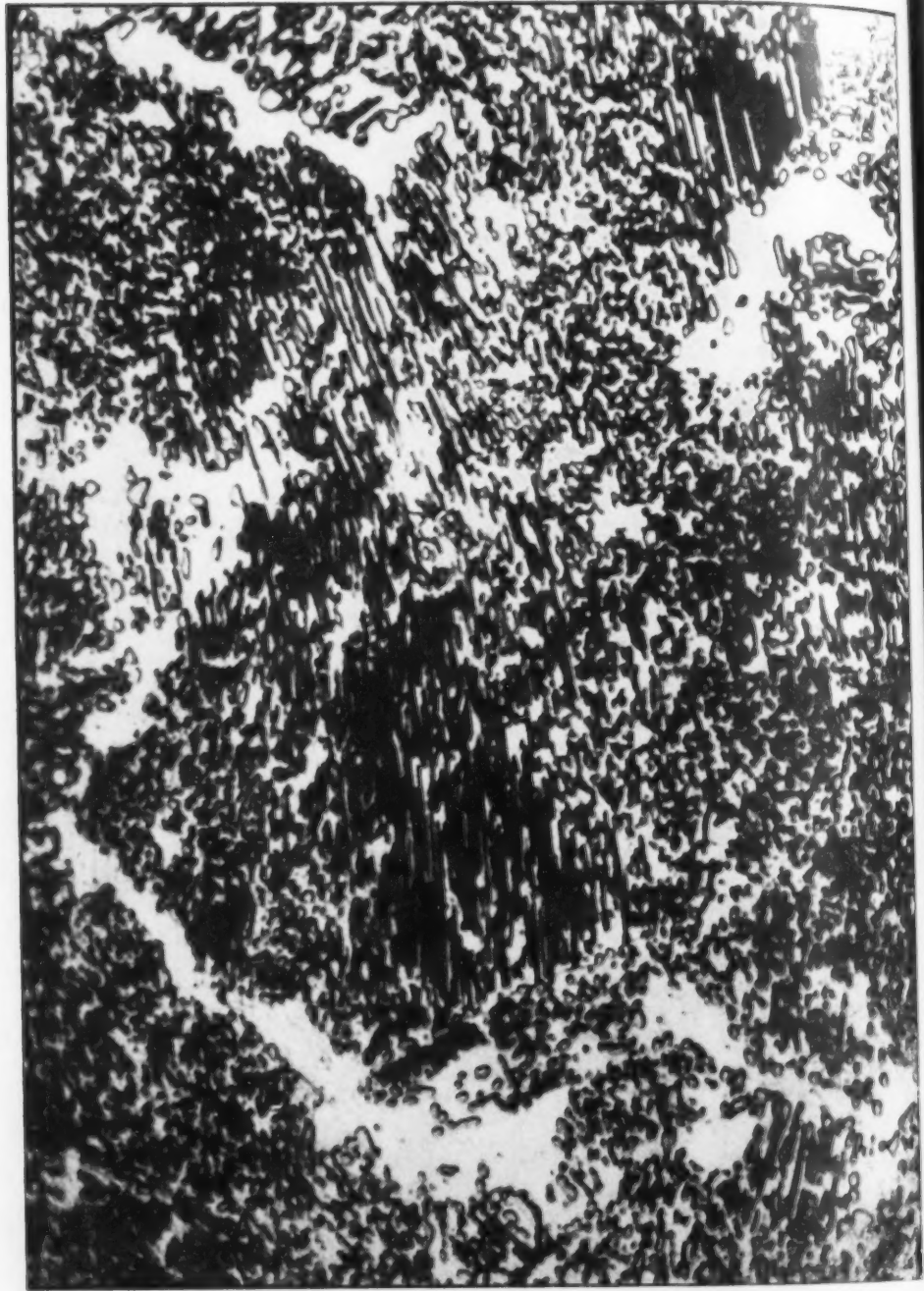
Fig. 4—Series I
Magnification 1000 X
Steel Forging Y7465 D

Analysis   Longitudinal Test
Carbon .... .57
Manganese .... .75   Yield 43,000
Sulphur .... .041   Ultimate 88,200
Phosphorus .... .036   Per Cent Elongation........... 26.
Silicon .... .240   Per Cent Reduction........... 46.
          Treatment 1250 Degrees Fahr. Held 36 Hours Cooled in Furnace.

This forging was then annealed at 1250 degrees Fahr., and held at this temperature for thirty-six hours. The physical properties show an increase in ductility, and photomicrograph, Fig. 4, shows a partial spheroidization. This temperature was used to show that there was a corroding of the cementite at a temperature which is below Ac_1 point of the steel as a whole.

Series II (Figs. 5, 6, 7) is of a forging $24\frac{1}{8}$ inches in diameter, 180 11/16 inches long, made from a 31-inch ingot, test bars taken radially. Photomicrograph in Fig. 5 shows the typical lamellar pearlite after an anneal at 1475 degrees Fahr. for eight hours. The ductility is very low. A further treatment at 1250 degrees Fahr. for fifty-six hours shows a great increase in ductility and the practically completed spheroidizing of the cementite of the pearlite, as shown in photomicrographs of Figs. 6 and 7. Fig. 7 shows an area evidently of lower or more uniform concentration, which shows portions of the cementite lamellæ undissolved at this temperature.

Series III (Figs. 8 and 9) is taken as a check on Series II, it being on a forging of the same dimensions, from the same size ingot and of practically the same analysis. Photomicrographs in Figs. 8 and 5 correspond, having had the same treatment. Photomicrograph in Fig. 9 is taken after a treatment similar to Figs. 6 and 7. It does not show the definition of the spheroidizing, as do Figs. 6 and 7, but this is partially due to the section photographed. It was taken at the junction of several pearlitic grains of different orientation. This shows the practical obliteration of this orientation by spheroidizing. The ductility again shows a marked increase.

Series IV (Figs. 10, 11, 12) was made on a forging of the same size and from an ingot of the same dimensions and approximate analysis as used in Series II and Series III. Photomicrograph in Fig. 10 was taken after an anneal for grain refinement at 1475 degrees Fahr., maintained for ten hours.

Photomicrographs in Figs. 11 and 12 were taken after anneals of 1250 degrees Fahr., maintained for forty-eight and seventy-two hours, respectively. They show a greater and greater coalescing of the pearlitic cementite with time even at a temperature which is below the Ac_1 point of the steel as a whole. The ductility increases with the spheroidization.

Fig. 5—Series II

Magnification 1000 X

Steel Forging Y7531 A

Analysis		Radial Test	
Carbon	.45		
Manganese	.53	Yield	38,500
Sulphur	.028	Ultimate	84,000
Phosphorus	.027	Per Cent Elongation	18.
Silicon	.168	Per Cent Reduction	26.

Treatment 1475 Degrees Fahr.　Held 8 Hours.　Cooled in Furnace.
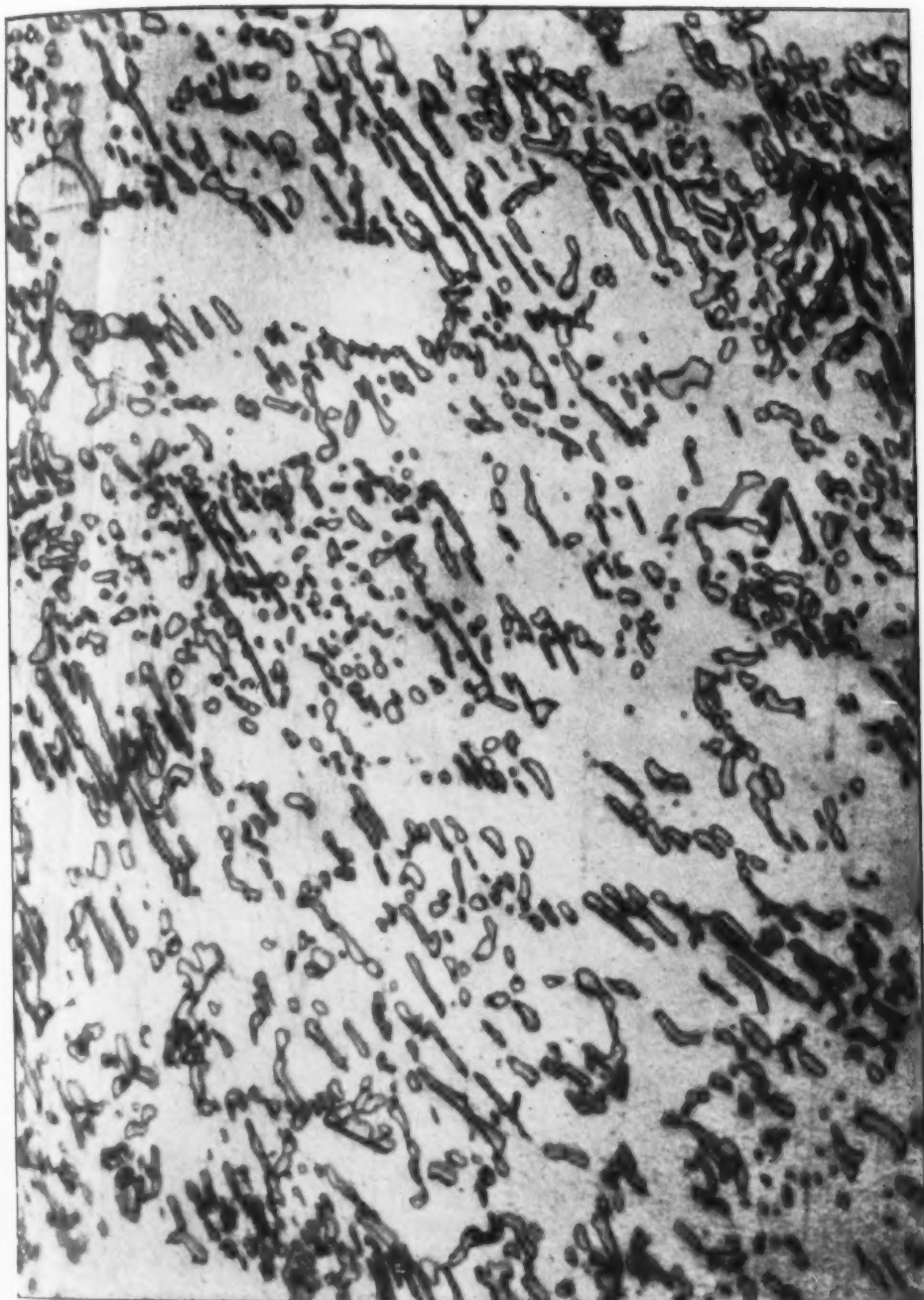
Fig. 6—Series II
Magnification 1000 X
Steel Forging Y7531 C

Analysis		Radial Test	
Carbon	.45		
Manganese	.53	Yield	32,200
Sulphur	.028	Ultimate	66,000
Phosphorus	.027	Per Cent Elongation	27.
Silicon	.168	Per Cent Reduction	42.

Treatment 1250 Degrees Fahr.   Held 56 Hours.   Cooled in Furnace.

Fig. 7—Series II

Magnification 1000 X

Steel Forging Y7531 C

Additional View of Same Section as Shown in Fig. 6.
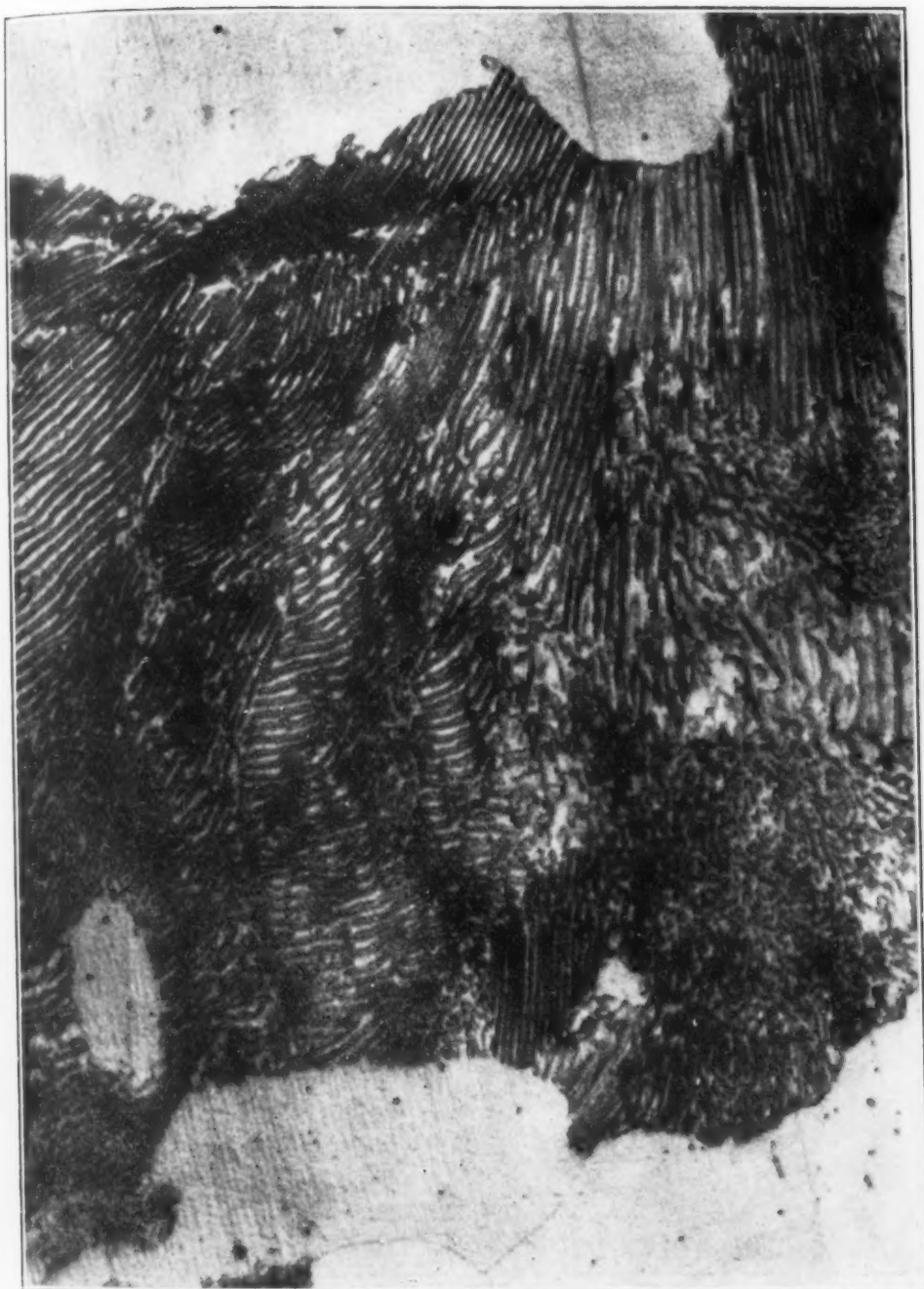
Fig. 8—Series III

Magnification 1000 X

Analysis		Steel Forging Y7532	
Carbon	.45	Radial Test	
Manganese	.53	Yield	40,300
Sulphur	.028	Ultimate	83,700
Phosphorus	.023	Per Cent Elongation	19.5
Silicon	.168	Per Cent Reduction	30.

Treatment 1475 Degrees Fahr.   Held 8 Hours.   Cooled in Furnace.
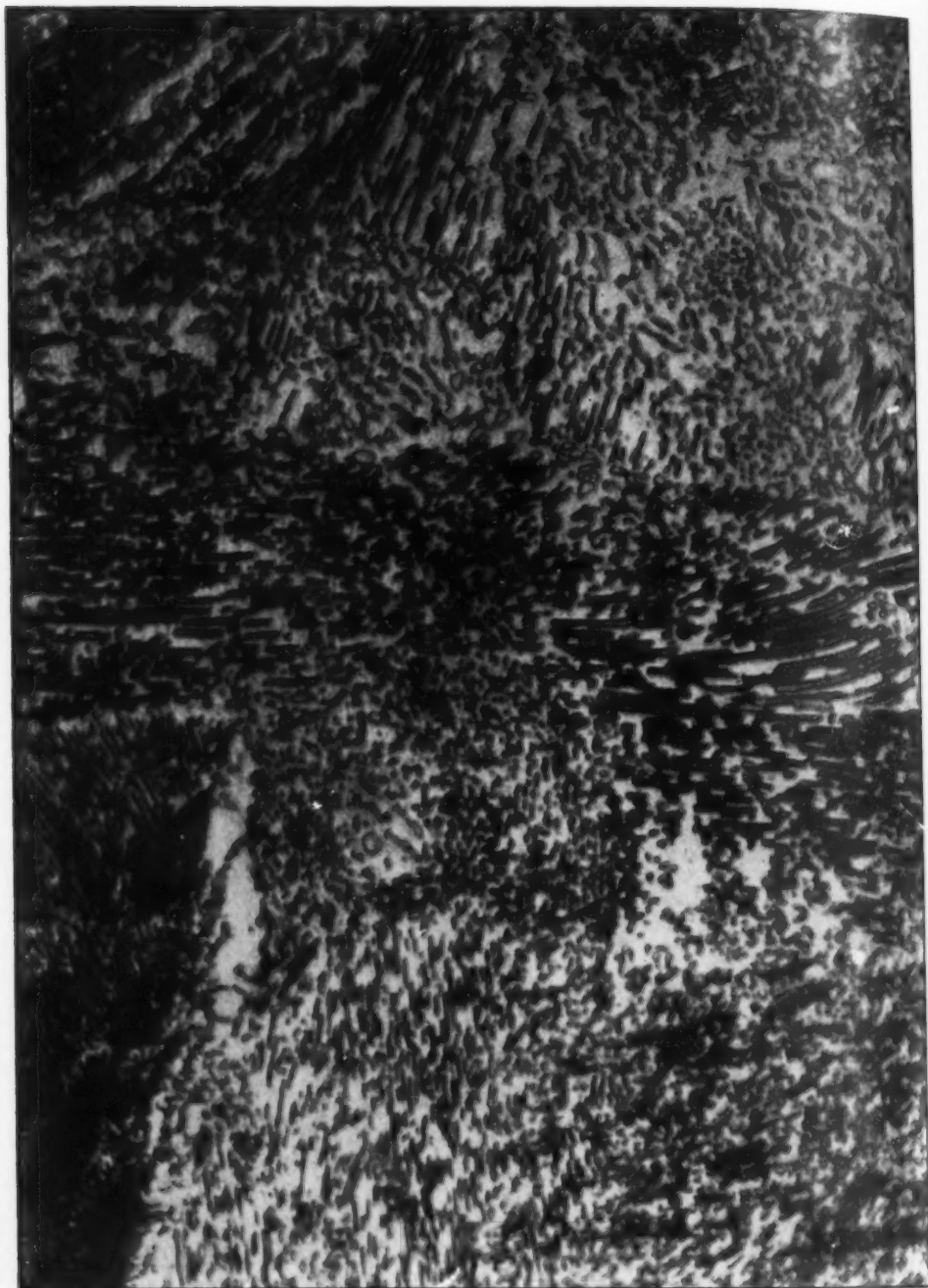
Fig. 9—Series III
Magnification 1000 X
Steel Forging Y7532 B

Analysis		Radial Test	
Carbon	.45		
Manganese	.53	Yield	35,000
Sulphur	.028	Ultimate	78,300
Phosphorus	.023	Per Cent Elongation..........	25.
Silicon	.168	Per Cent Reduction...........	39.

Treatment 1250 Degrees Fahr.   Held 56 Hours.   Cooled in Furnace.

Fig. 16—Series IV
Magnification 1000 X
Steel Forging Y7453 A

Analysis		Radial Test	
Carbon	.45		
Manganese	.57	Yield	40,250
Sulphur	.027	Ultimate	84,850
Phosphorus	.025	Per Cent Elongation	19.5
Silicon	.140	Per Cent Reduction	28.

Treatment 1475 Degrees Fahr.   Held 10 Hours.   Cooled in Furnace.

Fig. 11—Series IV
Magnification 1000 X
Steel Forging Y7453 D

Analysis		Radial Test	
Carbon	.45		
Manganese	.57	Yield	35,100
Sulphur	.027	Ultimate	72,300
Phosphorus	.025	Per Cent Elongation	24.5
Silicon	.140	Per Cent Reduction	34.

Treatment 1250 Degrees Fahr. Held 48 Hours. Cooled in Furnace.
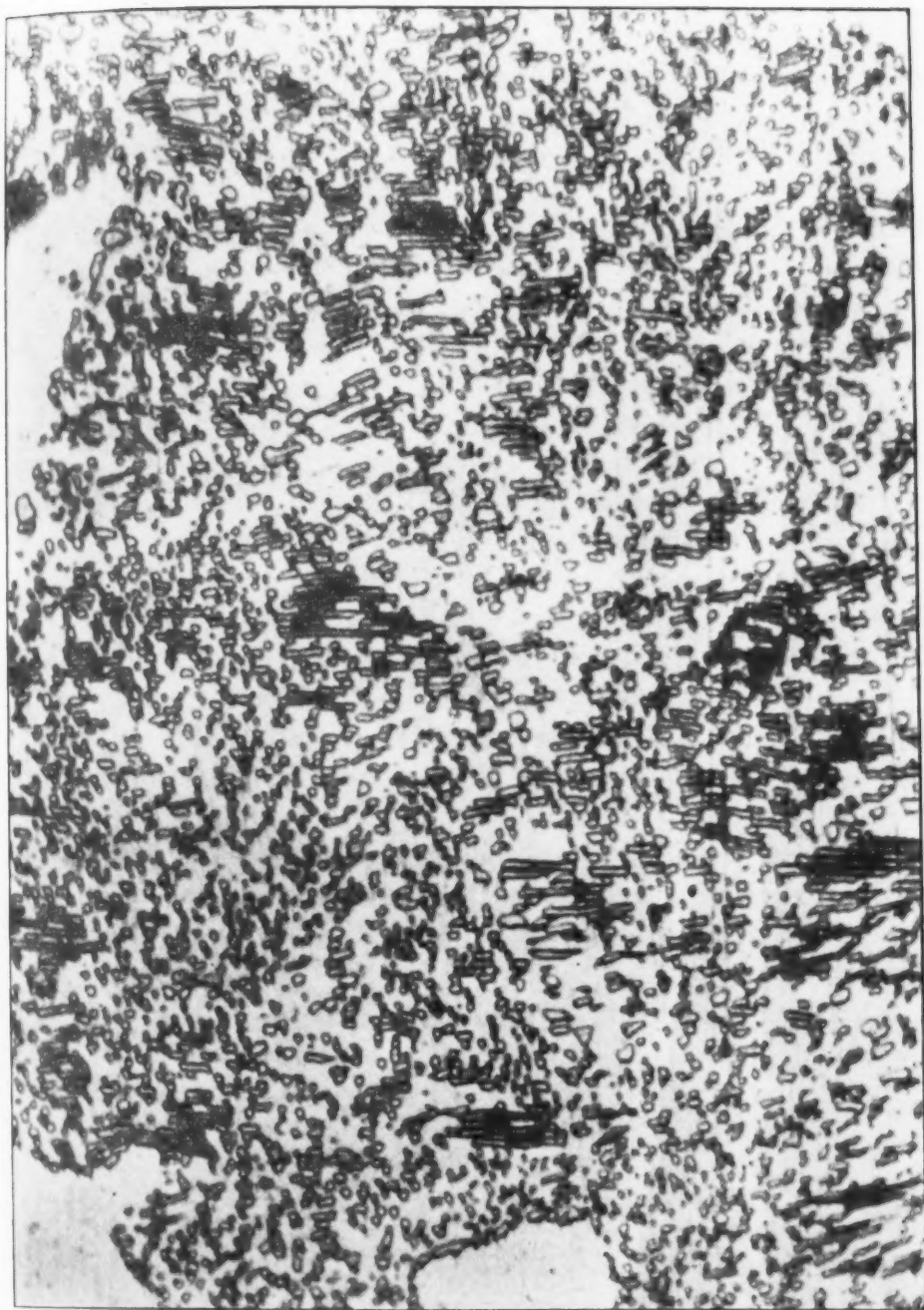
Fig. 12—Series IV
Magnification 1000 X
Steel Forging Y7453 E

Analysis		Radial Test	
Carbon	.45		
Manganese	.57	Yield	33,200
Sulphur	.027	Ultimate	69,500
Phosphorus	.025	Per Cent Elongation	30.
Silicon	.140	Per Cent Reduction	52.

Treatment 1250 Degrees Fahr. Held 72 Hours. Cooled in Furnace.

Series V (Figs. 13, 14, 15) is again of a similar forging in all respects to Series II, Series III and Series IV. Photomicrograph, Fig. 13, is taken after an anneal at 1480 degrees Fahr., maintained for twelve hours. The similarity and lack of ductility of the radial bars of Figs. 5, 8, 10 and 13 of these characteristic lamellar pearl-itic steels should be noted. This forging was then annealed at 1200 degrees Fahr., maintained for fifteen hours, and the photo-micrograph, as shown in Fig. 14, together with the physical re-sults, correspond to Fig. 13. It is evident that this temperature is not sufficient to cause the solution of any of the pearlitic cementite in the ferrite, and for this reason no spheroidization takes place.

After annealing this forging at 1290 degrees Fahr. for a period of eight hours, spheroidization, as shown in Fig. 15, is well under way, and the ductility of the radial bar has, in consequence, increased.

Series VI (Figs. 16 and 17) is taken of a forging 30 inches in diameter, forged from a 42-inch ingot. Fig. 16 shows the re-sult of what would be called a commercial treatment, although the complete spheroidization has not taken place. This treatment consisted of grain refinement by heating to 1500 degrees Fahr., maintained for eight hours, followed by reheating to 1290 degrees Fahr., which was maintained for four hours. This time, for a section as large as this, could well be extended. The ductility of this transverse test is good.

Photomicrograph in Fig. 17 was taken after this forging had been re-annealed at 1500 degrees Fahr. for a period of five hours. It can be noted that the pearlite has again become lamellar, with the exception of several small areas in which the cementite is still spheroidal. The ductility of the transverse test has decreased, as shown by the physical tests.

Figs. 18 and 19 are photomicrographs from large cast steel cylinders, weighing approximately 20,000 pounds and having a wall thickness of about 3½ inches. The pieces have been normal-ized by a heating to 1650 degrees Fahr., maintained ten hours and air cooled. This treatment was for the purpose of breaking up the ingotism due to casting. A grain refinement treatment of 1550 degrees Fahr. maintained for ten hours, followed by the "loneal" of 1290 degrees Fahr. for three hours and air cooled
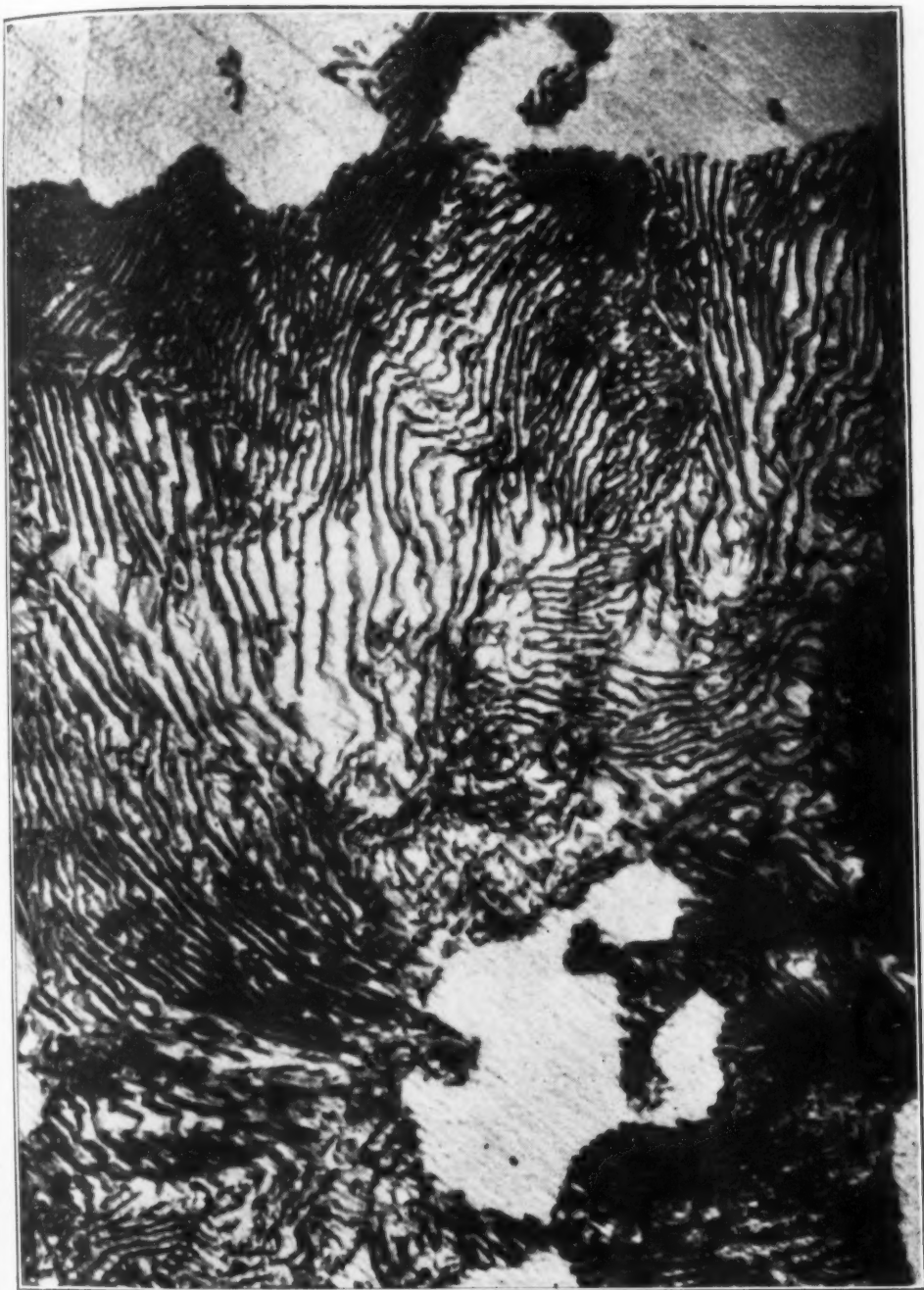
Fig. 13—Series V
Magnification 1000 X
Steel Forging Y7773 A

Analysis		Radial Test	
Carbon	.43		
Manganese	.54	Yield	42,700
Sulphur	.030	Ultimate	87,500
Phosphorus	.030	Per Cent Elongation	17.
Silicon	.168	Per Cent Reduction	26.

Treatment 1480 Degrees Fahr.   Held 12 Hours.   Cooled in Furnace.
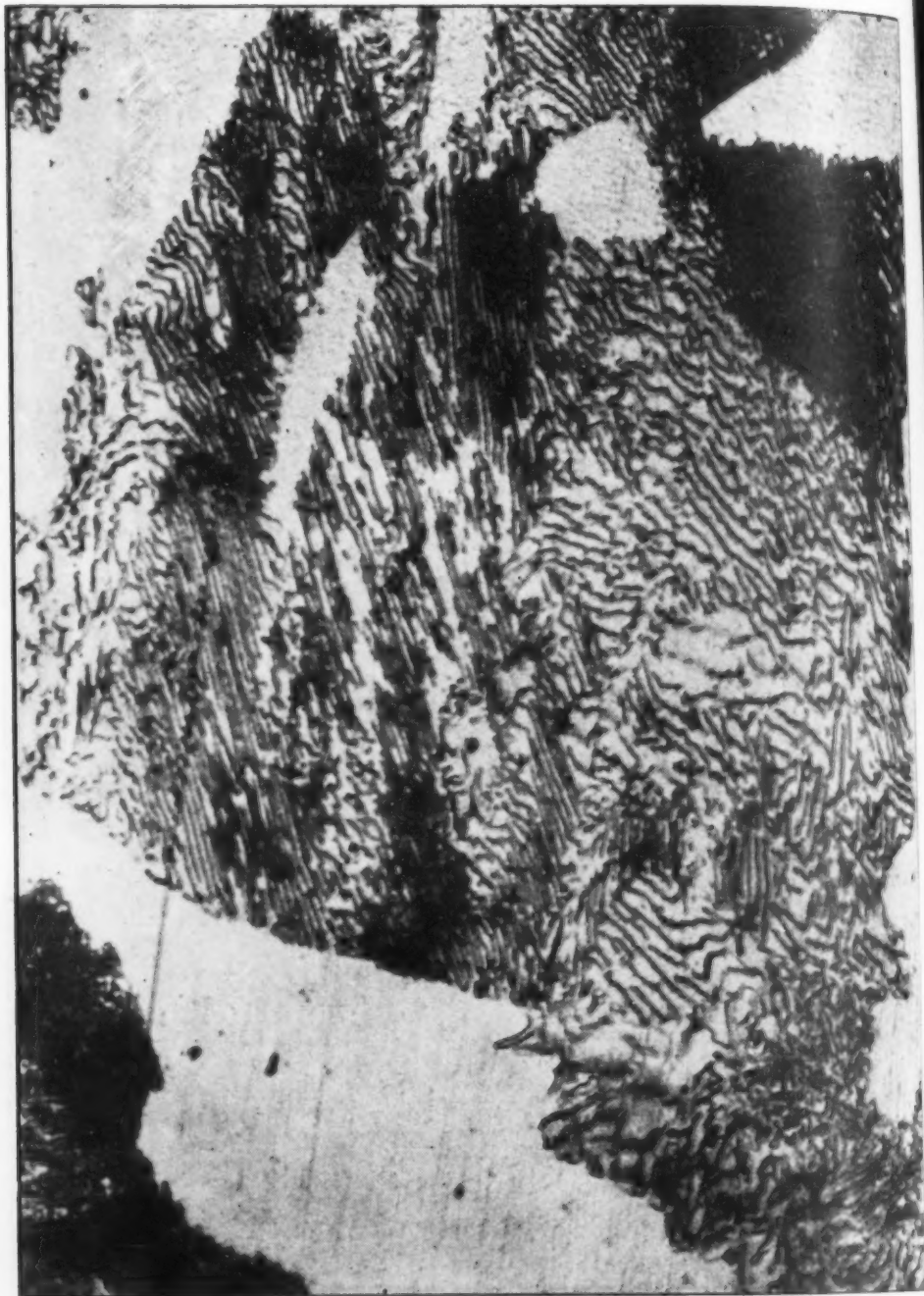
Fig. 14—Series V
Magnification 1000 X
Steel Forging Y7773 B

Analysis		Radial Test	
Carbon	.43		
Manganese	.54	Yield	43,000
Sulphur	.030	Ultimate	88,500
Phosphorus	.030	Per Cent Elongation	17.
Silicon	.168	Per Cent Reduction	26.

Treatment 1200 Degrees Fahr.   Held 15 Hours.   Cooled in Furnace.
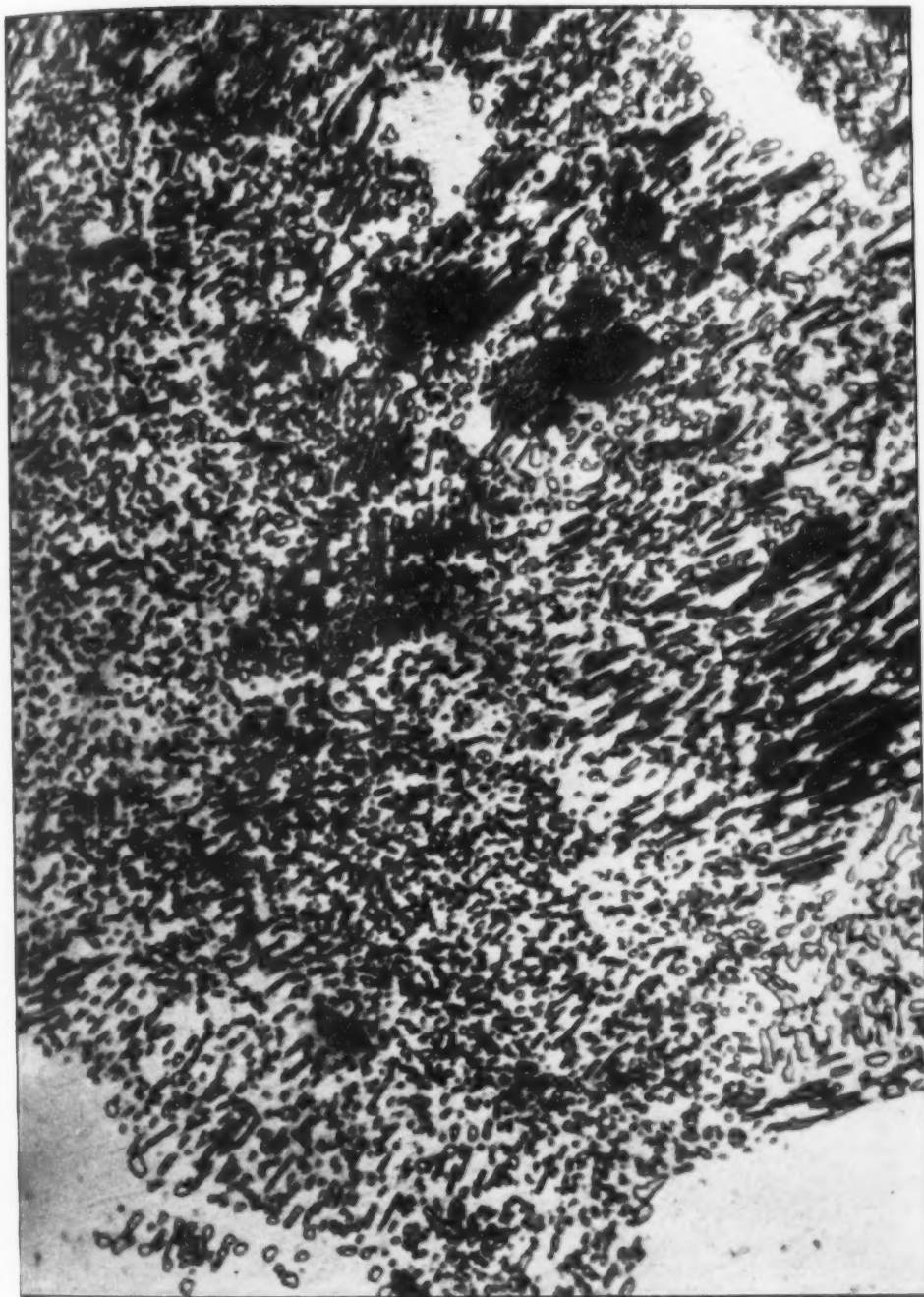
Fig. 15—Series V
Magnification 1000 X
Steel Forging Y7773 E

Analysis		Radial Test	
Carbon	.43	Yield	39,400
Manganese	.54	Ultimate	80,450
Sulphur	.030	Per Cent Elongation	26.
Phosphorus	.030	Per Cent Reduction	41.
Silicon	.168		

Treatment 1290 Degrees Fahr.   Held 8 Hours.   Cooled in Furnace.

Fig. 16—Series VI
Magnification 1000 X
Steel Forging W20213

Analysis		Transverse Test	
Carbon	.46		
Manganese	.58	Yield	35,500
Sulphur	.027	Ultimate	77,700
Phosphorus	.014	Per Cent Elongation	27.
Silicon	.155	Per Cent Reduction	44.

Treatment 1500 Degrees Fahr. Held 8 Hours. Furnace Cooled. 1290 Degrees Fahr. Held 4 Hours. Air Cooled.
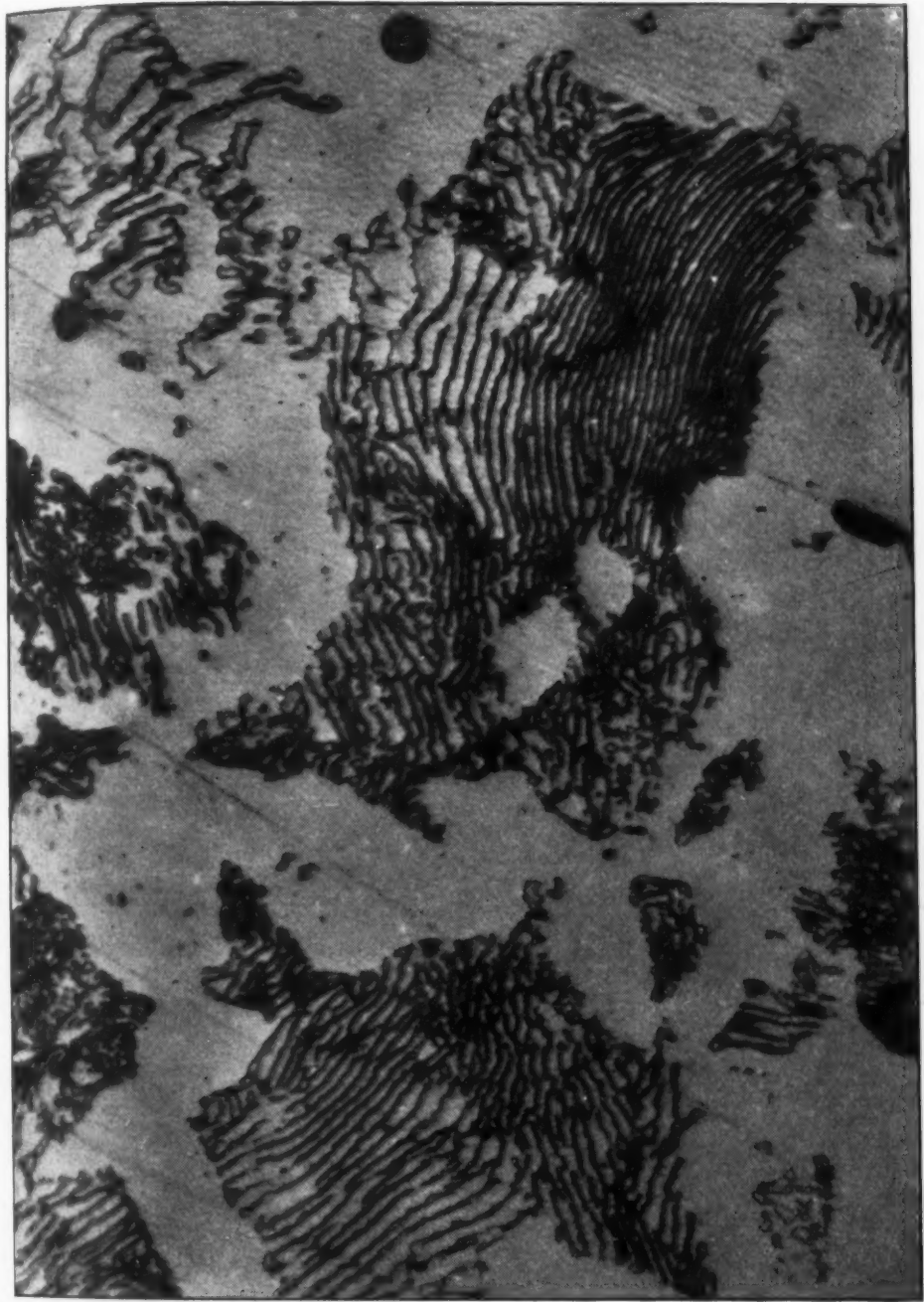
Fig. 17—Series VI
Magnification 1000 X
Steel Forging W20213

Analysis		Transverse Test	
Carbon	.46		
Manganese	.58	Yield	39,100
Sulphur	.027	Ultimate	80,600
Phosphorus	.014	Per Cent Elongation..........	23. 5
Silicon	.155	Per Cent Reduction...........	39.

Treatment 1500 Degrees Fahr.   Held 5 Hours.   Furnace Cooled.

Fig. 18

Magnification 1000 X

Cast Steel Cylinder W20163

Analysis		Radial Test	
Carbon	.28		
Manganese	.72	Yield	36,500
Sulphur	.036	Ultimate	70,000
Phosphorus	.041	Per Cent Elongation	30.5
Silicon	.30	Per Cent Reduction	50.

Treatment 1650 Degrees Fahr. Held 10 Hours. Air Cooled. 1550 Degrees Fahr. Held 10 Hours. Furnace Cooled. 1290 Degrees Fahr. Held 3 Hours. Air Cooled.
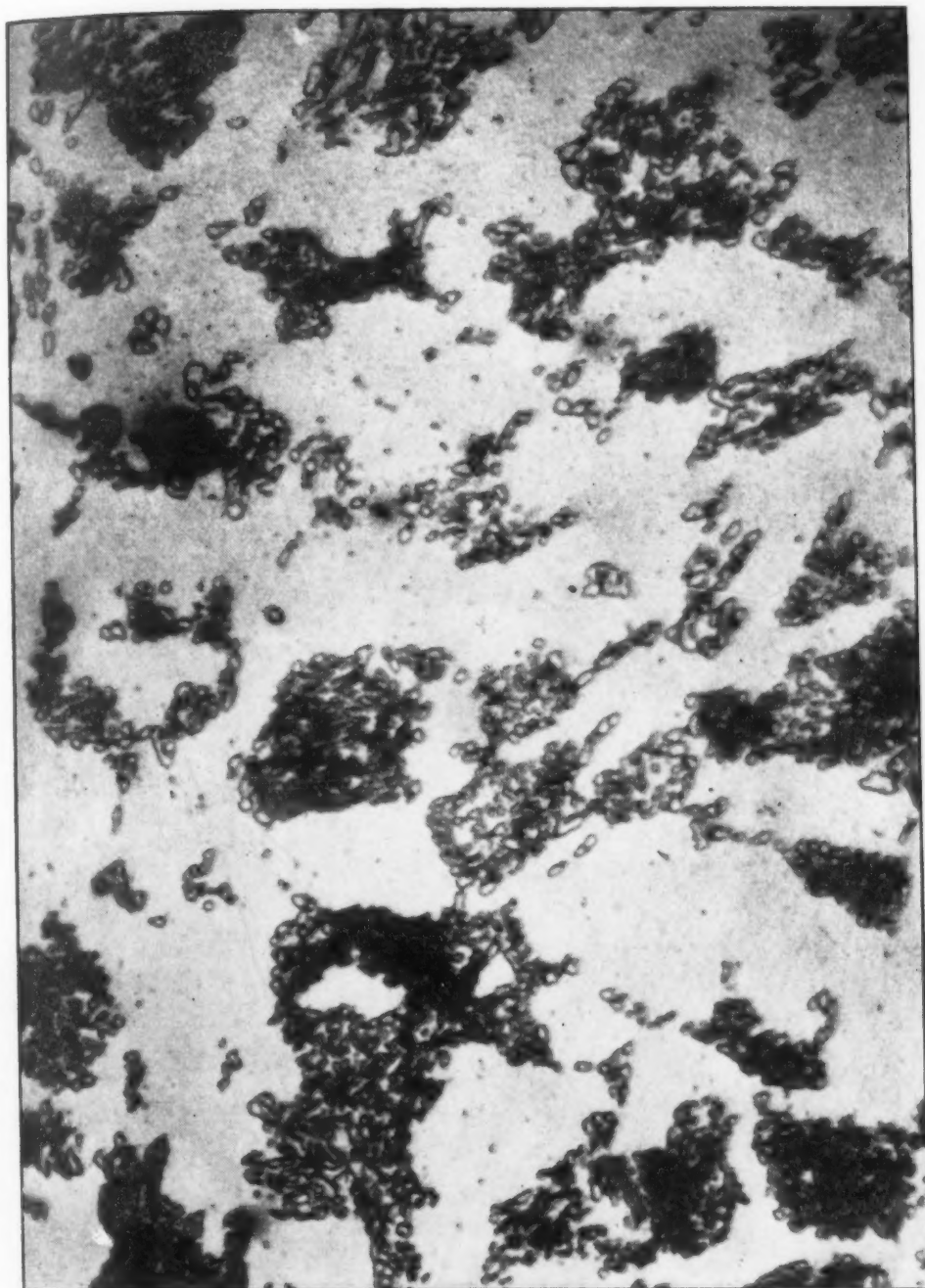
Fig. 19
Magnification 1000 X
Cast Steel Cylinder W20146

Analysis		Radial Test	
Carbon	.30		
Manganese	.67	Yield	42,200
Sulphur	.033	Ultimate	75,100
Phosphorus	.039	Per Cent Elongation	29.5
Silicon	.31	Per Cent Reduction	46.

Treatment 1650 Degrees Fahr. Held 10 Hours. Air Cooled. 1550 Degrees Fahr. Held 10 Hours. Furnace Cooled. 1290 Degrees Fahr. Held 3 Hours. Air Cooled.

Fig. 20
Magnification 1000 X
Cast Steel Casting H5238

Analysis		Radial Test	
Carbon	.28		
Manganese	.69	Yield	30,550
Sulphur	.037	Ultimate	65,800
Phosphorus	.032	Per Cent Elongation	32.
Silicon	.33	Per Cent Reduction	49.

Treatment 1600 Degrees Fahr. Held 20 Hours. Furnace Cooled. 1250 Degrees Fahr. Held 18 Hours. Furnace Cooled.

was used. The structure shows the spheroidization of the cement-
ite and the physical results give excellent ductility. All test bars
were drilled from the casting and were not coupon bars. Photo-
micrograph of Fig. 20 is of a steel casting weighing 100,000 pounds
and the time of the treatments used was necessarily increased. The
physical test bar drilled from the casting shows excellent ductility.

DISCUSSION

In the results given, the authors have found that the ductility,
especially in transverse and radial tensile test bars, is greatly in-
creased by this spheroidizing treatment, and in no case was there
found the spheroidized cementite in the large harmful areas to
which Howe refers. It was also found that the physical tests taken
in the various directions in reference to the line of work in forg-
ings or to the surface in castings, tend to become the same.

On examining a number of specimens it was noted that the
formation of a majority of the lamellæ of the pearlitic constituent
bears a definite relation to the direction of work in forgings or
to the surface of cooling in castings. Excluding from considera-
tion the effect of non-metallic inclusions, it is this relation of the
lamellæ parallel to the direction of work or surface which causes
the transverse and radial tests of annealed steels to be less ductile
than the longitudinal.

Charpy[11] showed that this difference could be minimized in
forgings by reducing the amount of working done in the forging
operation, and suggested that this amount of work be reduced
where ductility and higher impact figures were desired in trans-
verse directions. The authors have found, within reasonable lim-
its, that this ductility in transverse and radial directions can be
obtained by spheroidizing the pearlitic constituent and thus re-
ducing shortness obtained by cutting across the pearlitic lamellæ
of annealed steels.

In Tables I, II, III and IV are some figures of three sets of
tests in which bars were taken both tangentially, radially and
longitudinally after the material had been spheroidized.

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[11]"Influence of Hot Deformation on the Qualities of Steel," by George Charpy, *Journal*
of the Iron and Steel Institute, 1918.

In cast steels (and undoubtedly in forged steel, to some extent) the cementite lamellæ of the pearlite bear a relation to the cooling surface; and it is, therefore, possible to get different results from

Table I

Shaft No. W-20,155

		Per Cent
ANALYSIS—Carbon	....	0.31
Manganese	....	0.55
Phosphorus	....	0.034
Sulphur	....	0.028
Silicon	....	0.155

Ingot diameter 48 inches   Shaft diameter 24 inches   Coef. of Working 4

	Yield Point	Ultimate	Per Cent Elongation	Per Cent Reduction
Longitudinal ...	47,100	78,400	24	44
Tangential	40,000	76,200	23	42
Radial	41,300	75,000	22	37

Table II

Shaft No. W-20,159

		Per Cent
ANALYSIS—Carbon	....	0.31
Manganese	....	0.51
Phosphorus	....	0.026
Sulphur	....	0.030
Silicon	....	0.153

Ingot diameter 36 inches   Shaft diameter 20 inches   Coef. of Working 3.24

	Yield Point	Ultimate	Per Cent Elongation	Per Cent Reduction
Longitudinal ...	36,300	73,500	25	46
Tangential	35,700	70,500	28	42
Radial	36,700	71,500	25	45

tests cut in various directions from a casting. The shape and cooling effect of cores, chills, etc., greatly influence this condition. This difference of tensile results, however, is reduced to a minimum by spheroidizing.

The nature of formation of pearlite in lamellar form is one in which the material is highly stressed. It is only natural that these stresses will tend to neutralize each other and that the material will tend to undergo deformation in time. Any machining operation in which the material is strained, any heating, even

such slight variations as occur due to weather changes, will cause a rearrangement in the stress and thus a possible deformation of the material.

The nature of spheroidized pearlite is such that the material is in as near equilibrium as possible, and thus any machining or temperature changes will cause very little deformation.

In order to prove the above, the authors selected two large steel cylinders and annealed one to obtain the pearlite in lamel-

Table III

Shaft No. W-20,213

	Per Cent
ANALYSIS—Carbon	0.46
Manganese	0.58
Phosphorus	0.014
Sulphur	0.027
Silicon	0.155

Ingot diameter 42 inches   Shaft diameter 30 inches   Coef. of Working 1.96

	Yield Point	Ultimate	Per Cent Elongation	Per Cent Reduction
Longitudinal ...	37,300	77,750	27	44
Tangential	37,900	79,600	26	42
Radial	37,500	77,700	27	44

Table IV

Shaft No. W-20,208

	Per Cent
ANALYSIS—Carbon	0.43
Manganese	0.50
Phosphorus	0.020
Sulphur	0.029
Silicon	0.140

Ingot diameter 36 inches   Shaft diameter 30 inches   Coef. of Working 1.44

	Yield Point	Ultimate	Per Cent Elongation	Per Cent Reduction
Longitudinal ...	37,600	77,400	25	42
Tangential	40,500	76,800	26.5	41
Radial	37,100	75,700	26.5	42

lar form. On subsequent reheating to 800 degrees Fahr., they found dimension changes as high as 0.91 inches.

The other cylinder was given a loneal treatment, in which the cementite of the pearlitic constituent was spheroidized. After

many reheatings to 800 degrees Fahr., and after aging for approxi-
mately one year, the greatest dimension change was less than
0.004 inches.

Reinhardt and Cutler[12] found that tensile tests pulled imme-
diately after machining gave lower results than bars which were

Table V
Lamellar Pearlitic Steels

	Bars machined and immediately pulled	Bars machined and put in steam bath (212 degrees Fahr.) for 12 hours
Yield	49,450	48,100
Tensile	86,750	92,800
% Elongation	22.	25.5
% Reduction	41.	50.
Yield	54,500	47,050
Tensile	88,450	87,500
% Elongation	23.	26.5
% Reduction	44.	55.
Yield	53,500	43,950
Tensile	78,100	79,200
% Elongation	22.	28.5
% Reduction	37.	60.

Table VI.
Spheroidized Cementite of Pearlite Constituent

	Bars machined and immediately pulled	Bars machined and put in steam bath (212 degrees Fahr.) for 12 hours
Yield	39,040	40,500
Ultimate	76,070	76,800
% Elongation	26.	26.5
% Reduction	41.	41.
Yield	38,950	37,900
Ultimate	77,550	79,600
% Elongation	26.5	26.
% Reduction	45.	44.

allowed to rest or were heated slightly. The present authors ob-
tained like results, as shown below in table V.

Jeffries[13] suggested the possibility of a low critical point due
to this and similar phenomena.

[12]"Effect of Time and Low Temperature on the Physical Properties of Medium Carbon
Steel," by G. A. Reinhardt and H. L. Cutler. *Transactions* of The American Institute of
Mining and Metallurgical Engineers, 1919.
[13]"Physical Changes in Iron and Steel below the Thermal Critical Range," by Zay Jeffries,
Transactions of the American Institute of Mining and Metallurgical Engineers, Vol. XVVII.
p. 56, 1922.

The authors believe the above results to be due to the stressed condition of the material, especially the pearlitic constituent, and that aging or slight heating tends to balance this stress.

In bars of material which have had the cementite of the pearlitic constituent spheroidized, this condition does not exist, as the internal stress is reduced to a minimum. This is shown in Table VI of tests made on spheroidized steel. These tests were made in a like manner to the preceding ones in lamellar pearlite steel.

The difference in physical results of steels of similar analysis made by the basic open hearth and acid open hearth process are well known. This difference between steels made by these two processes was called forcefully to the authors' attention in some work on deep etching when a difference in solubility was noted between acid and basic steels.

The authors have noted, although at the present time the complete results are not available, that the cementite constituent of the pearlite appears to differ in steels made by these two processes and it is believed that this variation in the cementite causes the difference in solubility. This variation in the cementite of the pearlite constituent, whether due to oxygen, difference in carbon, or some other cause, does not appear to be noticeable when the cementite has been spheroidized. In this latter condition steels of like analysis made by the basic and acid open hearth processes do not appear to manifest different physical tensile properties.

The authors expect to have this characteristic result of spheroidizing, together with some results of fatigue tests, for fuller consideration in the near future.

SUMMARY

1. When the cementite of the pearlitic constituent is spheroidized, the tensile properties taken in various directions in reference to the line of work in forgings or to the surface in castings tend to become the same.

2. The transverse and radial ductility is greatly increased by spheroidizing.

3. Within reasonable limits, the effect of forging reduction upon the ductility of transverse, longitudinal and radial tests is eliminated.

4. The distortion which takes place in pearlitic steels with aging or low temperature variations is reduced to a minimum when the cementite of the pearlitic constituent is spheroidized.

In closing, the authors wish to express their appreciation of the able assistance of Harold Stein and Rexford Krueger in preparing the specimens and photomicrographs for this investigation.

APPLICATION OF X-RAY CRYSTAL ANALYSIS TO METALLURGY

By W. P. Davey

Abstract

*This paper outlines the methods used in applying
X-ray crystal analysis to metallurgy and gives some of
the outstanding results so far obtained.*

*Figures illustrating atom arrangements and a diagram
of the method used in obtaining X-ray spectroscopic pho-
tographs are included.*

ALL SOLID metals and their alloys are crystalline. This means
that their atoms are arranged in space according to some
definite geometrical pattern, so that if we could see them as they
exist in the crystal we would have a picture something like a lot
of ball bearings systematically packed in a box. The arrangement
of the atoms of a metal in a crystal, and the distances between
atomic centers are just as characteristic of that metal as its density
or melting point. A consideration of the configuration of the
atoms of a given metal or alloy leads to definite ideas as to certain
of its physical properties, such as ductility, and it is to be ex-
pected that further investigations will give a rational explanation
of still other properties. Still other studies of crystal structure
are beginning to give us a picture of what a solid solution really
is. Crystal analysis, therefore, affects so deeply the very founda-
tions of metallurgy and metallography that it will be worth our
while to review the way in which X-rays are used in analyzing
the inner structure of a crystal, and the application of the results
of crystal analysis to metallurgical problems.

FINDING THE STRUCTURE OF A CRYSTAL

The determination of the structure of a crystal is a two-stage
process. First, it is necessary to determine the distance between

the various planes of atoms in the crystal; second, the arrange-
ment of atoms in space must be found which will give quantitatively
these interplanar distances.   The first step involves the accurate
measurement of extremely minute distances, of the order of 10^{-8}
centimeters:—the second involves systematic cut-and-try methods
supplemented by experience.   These two steps will be discussed in
detail.

The measurement of a small distance is easiest accomplished
by measuring some larger distance which is related to the small
distance, by some known law.   For instance, a distance of a thou-
sandth of an inch may be measured in terms of the movement of
the head of the screw of a micrometer if only we know the pitch
of the screw and the diameter of the screw head.   The distances
between planes of atoms in crystals are much too small to be meas-
ured by the movement of a micrometer head, but they may be
measured easily in terms of the deflections of a beam of X-rays
of known wave-length.   Bragg's Law,[1] which gives the relation
between the interplanar distances in the crystal, the wave-length
of X-rays, and the angle of bending of the X-rays is

$$d = \tfrac{1}{2}\,\frac{n\,\lambda}{\sin\,\phi/2}$$

where λ is the wave-length of the X-rays.   In this country the
X-rays commonly used in crystal analysis are the Ka_1,
and Ka_2 lines of molybdenum.   Their wave-lengths are
given by Siegbahn as

$$Ka_1 = 0.7076 \times 10^{-8} \text{ cm}$$
$$Ka_2 = 0.7119 \times 10^{-8} \text{ cm}$$

n is any small positive integer.   It gives the "order" of
diffraction.

ϕ is the angle through which the X-rays are bent by
diffraction from the crystal.   It is this value which is
measured experimentally in crystal analysis.

d is the interplanar spacing for some one family of planes
in the crystal.

It is usually necessary to determine the interplanar spacings for

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[1] A complete derivation of Bragg's Law will be given in the General Electric Review.
October, 1924.

a large number of families of planes. This is easiest done by the so-called "powder" method developed independently in this country by Hull, and in Europe by Debye and Sherrer. With this method the material to be examined must contain a large number of crystals or "grains." These must have a random orientation so that representatives of every family of planes will be found at every possible angle to the direction of the incident beam of X-rays.
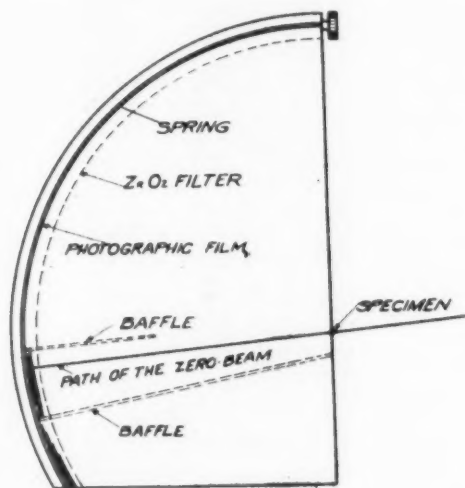

Fig. 1—Film and Specimen Holder for Crystal Analysis.

This insures that some representatives of each family of planes will be oriented at the correct angle to diffract X-rays of the wavelength employed in the experiment. In case the grain-size of a sample of metal or alloy is small enough (about 0.002 inch) it is usually sufficient to have the incident beam of X-rays strike on a narrow edge of the specimen. If the grain-size is too large, very fine filings must be made which are either packed into a capillary glass tube or pasted together into a sheet with celluloid varnish. The beams of X-rays diffracted by the various families of planes in the crystal, impinge upon a photographic film (See Fig. 1) bent into the arc of a circle whose center is the specimen under investigation. The film, Fig. 2, therefore furnishes a means of determining the angle φ through which the X-rays have been bent by each of the families of planes. When these values of φ have been substituted in Bragg's equation, the interplanar distance for each family is at once obtained. This completes the first stage of the determination of the structure of the crystal.

Tungsten
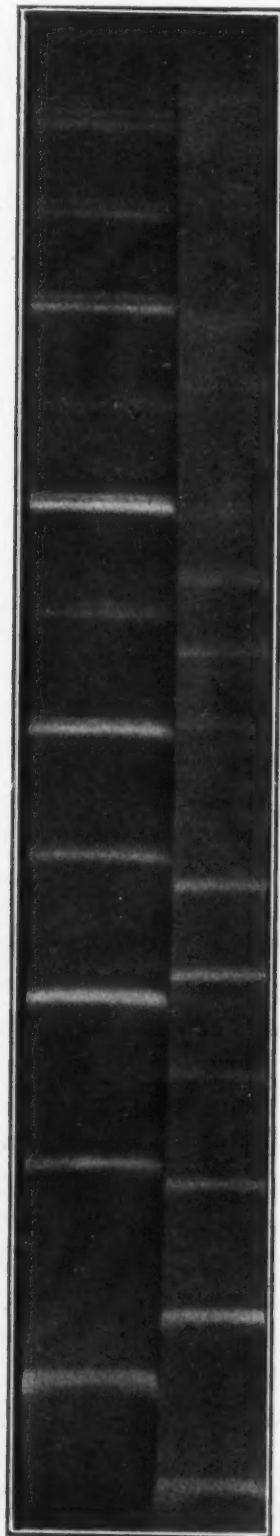
Sodium Chloride

Fig. 2—Diffraction Patterns of Tungsten and of Sodium Chloride. The diffraction pattern of Sodium Chloride is taken on the lower half of every film from which precision measurements are to be made. It serves as a means of calibrating the film, thus avoiding many sources of error. In this connection see Physical Review, *19*, 538, (1922).

The second stage may be illustrated as follows: Suppose that the trees of an orchard are planted according to some systematic geometrical scheme of polygons. Then it will be possible to find many directions through the orchard such that the trees appear to stand in parallel rows. The relative distances between rows of trees depends upon the geometrical design of the orchard. For instance, if the trees are laid out so that there is a tree at each corner of an imaginary square, the distance between rows viewed along the diagonals of the square will be $\frac{1}{2}\sqrt{2} = 0.7$ times the distance between rows viewed along the sides of the squares. If, however, the trees are planted so that they are not only at the corners of the imaginary squares but also at the centers of the squares, the diagonal rows will appear to be $\sqrt{2} = 1.4$ times as far apart as the rows viewed along the sides of the squares. It is evident, then, that if the relative distances between the various rows of trees are known, it is possible by systematic cut-and-try methods to find the geometrical design in accordance with which the orchard was planted. If the absolute distances are known, a map of the orchard may be drawn to scale.

The problem in crystal analysis is much the same as that of the orchard, except that there are three dimensions to deal with instead of two. It will be sufficient to say that the cut-and-try method has been so systematized for those crystal systems ordinarily found in metallurgical materials that the complete solution can be usually obtained in a few minutes.[2]

The solution is always checked by a calculation of the density of the crystal. The mass of the smallest unit of structure (unit-crystal) is calculated from the atomic weight, the number of atoms per unit-crystal, and the factor (1.649×10^{-24}), which changes units of atomic weight into grams. This is then divided by the volume of the unit-crystal as determined from the X-ray diffraction pattern.

The number of atoms per unit-crystal is determined as follows: (1) Suppose that the crystal is simple-cubic, as in Fig. 3. Then each atom lies at the meeting place of eight cubes, so that the eight corners of the cube contribute a net total of 8/8, or one atom to the unit-crystal. (2) If the crystal is body-centered cubic, as in Fig. 4, the atom at the center of the cube lies wholly inside the unit-cube,

[2] A. W. Hull and W. P. Davey, Physical Review 17, 549, (1921).

so that the unit-cube of a body-centered cubic lattice contains 8/8 plus 1, or a net total of two atoms. (3) If the crystal is face-centered cubic, as in Fig. 5, the atoms at the centers of the faces each contribute half an atom to the unit-cube, so that each unit-cube contains 8/8 plus 6/2, or a net total of four atoms. Similarly the number of atoms per unit-crystal for other structures may be calculated.

The only other crystal structure which is important from a a metallurgical point of view is the so-called "hexagonal close-
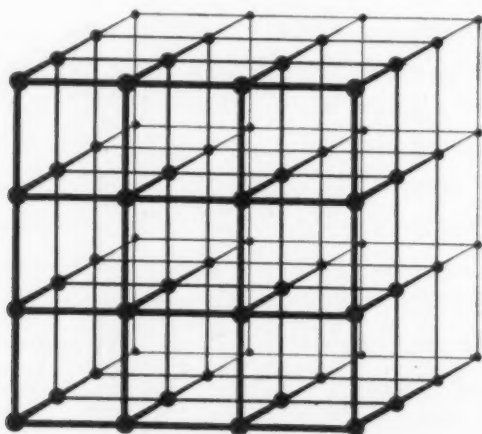

Fig. 3—Simple Cubic Lattice.

packed" lattice. If it were not for the prestige which comes from long usage, this name would probably be discarded for the more correct name of "triangular close-packed" lattice. Fig. 6 shows that this structure is composed of body-centered triangular prisms so placed together as to build up a hexagonal outline. It is evident from the figure that the atoms at the body-centers of the prisms may be regarded as themselves composing a family of triangular prisms. For this reason the triangular close-packed lattice is often spoken of as being composed of two interpenetrating families of simple triangular prisms.

Just as the trees of a properly planted orchard appear to stand in rows, in the same way the atoms of a crystal lie in planes. There have been many schemes proposed for naming these various planes. Only one of these, the "Miller," has survived, for it is the only one which lends itself easily to the mathematical calculations nec-

essary in crystal analysis. In the Miller nomenclature, each crystal
is given three "axes of reference," as in solid analytical geometry.
In the cubic system of crystals these axes are the three intersecting
edges of a unit-crystal. This gives three axes, called x, y, and z,
which are all at right angles to each other. In the triangular
close-packed lattice there are two axes, called x and y, making an
angle of 120 degrees with each other, and a third axis, the z axis,
is at right angles to both the other two. The various planes of
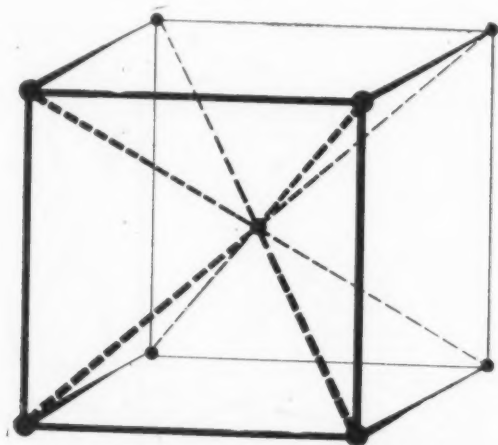atoms are then named by giving the reciprocals of the intercepts

Fig. 4—Unit Crystal of Body-Centered
Cubic Lattice.

of the plane on each of the three axes. These reciprocals are called
"indices." The unit of length employed in determining the inter-
cepts is called the "lattice parameter." In the cubic lattice it is
the edge of the unit-cube. To illustrate, the 3 2 1 plane cuts the
x-axis at a distance of $\frac{1}{3}$ unit from the origin of co-ordinates. It
cuts the y-axis at a distance of $\frac{1}{2}$ and the z-axis at a distance of 1.
The $\frac{3}{2}$ 1 $\frac{1}{2}$ plane, the 1 $\frac{2}{3}$ $\frac{1}{3}$ plane, etc., are parallel to the 3 2 1
plane and are members of the 3 2 1 family of planes. All members
of a family are given the simplest name of any member of the
family, thus the 3 2 1, the $\frac{3}{2}$ 1 $\frac{1}{2}$ and the 1 $\frac{2}{3}$ $\frac{1}{3}$ planes, etc., are
all called 3 2 1 planes. It is a little confusing at first to think in
terms of the reciprocals of the intercepts instead of the intercepts
themselves. The Miller scheme of nomenclature is, however, amply
justified because the reciprocals of the intercepts require the sim-
plest formulas for mathematical calculation of distances inside the

crystal. Since these calculations are inseparable from crystal analysis the Miller indices are now universally used in naming the planes of atoms in crystals.

In the triangular close-packed lattice the length of the edge of the triangular prism is, in general, not the same as the length of the side of the equilateral triangle which forms the base of the prism. There are, therefore, two units of measure for such crystals, one for the x- and y-axes and one for the z-axis. The ratio between these two units is called the "axial ratio" and is denoted
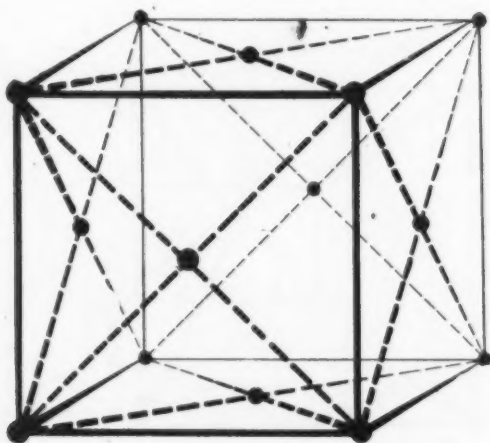
Fig. 5—Unit Crystal of Face-Centered Cubic Lattice.

by C. The use of the two units of measure is amply justified by the simplification which it permits in the necessary mathematical calculations.

Formerly, four axes were assigned to crystals belonging to the triangular close-packed lattice. The extra axis was in the plane of the x- and y-axes and was 120 degrees from both. Since the index for this extra axis is always the sum of the indices for the x- and y-axes and is measured in the negative direction along the extra axis, it is quite useless and is now generally discarded. Its place is, however, still indicated in the Miller indices by a dot. Thus the $11\bar{1}0$ plane is called the 1 1 . 0 plane. The use of the dot is justified by its convenience in case of transformation of the axes, but it will not be worth while to go more deeply into such a discussion at this time.

In connection with the writer's present work it has been nec-

essary to determine the crystal structure and dimensions of various metals when in a high state of purity. Some of these metals were obtained through the courtesy of Dr. G. Breit of the University of Minnesota, and of the Bureau of Standards. The aluminum was obtained from the Aluminum Company of America through the courtesy of J. D. Edwards, assistant director of research. The tungsten and molybdenum of high purity were obtained from the Research Laboratories of the National Lamp Works, General Electric Company, through the kindness of W. L. Enfield. The rest are from our laboratory stock of metallurgical materials. The ultimate source is given in Table I whenever known. These dimensions are as fundamental in crystal analysis as the measure-
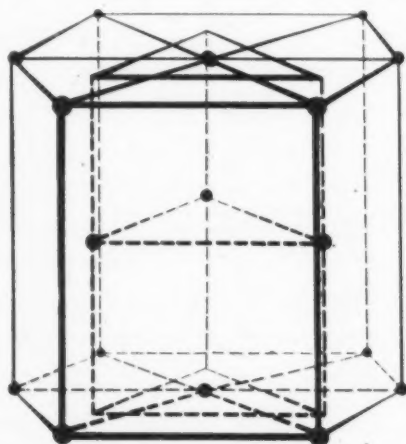
Fig. 6—Triangular Close-Packed Lattice.

ment of atomic weight in chemistry and of the ohm in electricity. Our results for the metals in most common use are given in Table I. Although we have used every care to make our measurements as accurate as possible, it is desirable that they be checked by some institution such as the Bureau of Standards, using material of at least equal purity.

THE EXPLANATION OF DUCTILITY

The results of experiment may be generalized by the statement that the ductile and malleable metals such as copper, silver, gold, aluminum, etc., have face-centered cubic structures, and that the metals which are relatively non-ductile, such as chromium and tungsten, have body-centered cubic structures. This rule is not, however, of universal application, for iron is reasonably ductile and has a body-centered cubic structure. The reason for this ex-

ception is not known,—it may be caused by some peculiar configuration of the valence electrons of iron. Single crystals of metals, such as zinc, which are ductile in the cold only in certain directions through the crystal, have a "hexagonal close-packed" structure.

The work of Mark, Polanyi and Schmid[3] and others make it

Table I

Metal	Source	% Purity	Structure	Lattice Parameter a	Density from X-Ray Data	Density from Literature
Al	1	99.97	F. C. C.	$4.046 \pm .004 \times 10^{-8}$ cm	$2.69 \pm .01$	2.708
Fe	2	"C.P."	B. C. C.	$2.861 \pm .003$	$7.86 \pm .02$	$7.85 - 7.88$
Fe	3	99.93		$2.855 \pm .003$	$7.92 \pm .02$	
Ni	4	99.55	F. C. C.	$3.499 \pm .003$	$9.04 \pm .03$	$8.6 - 8.93$
Cu	4	99.98	F. C. C.	$3.598 \pm .004$	$9.00 \pm .03$	8.937
	5	99.99		$3.596 \pm .004$	$9.02 \pm .03$	
Mo	4	98.	B. C. C.	$3.136 \pm .003$	$10.26 \pm .03$	10.28
	6	99.8		$3.142 \pm .003$	$10.21 \pm .03$	
Ag	4	99.9	F. C. C.	$4.058 \pm .004$	$10.64 \pm .03$	$10.50 - 10.53$
	7	99.999		$4.079 \pm .004$	$10.49 \pm .03$	
W	4	98.58	B. C. C.	$3.159 \pm .003$	$19.26 \pm .06$	$18.77 - 19.3$
	6	99.997		$3.155 \pm .003$	$19.32 \pm .06$	
	6	99.9995		$3.155 \pm .003$	$19.32 \pm .06$	
Pt	8		F. C. C.	$3.913 \pm .004$	$21.49 \pm .06$	$21.16 - 21.49$
Au	4	"24 caret"	F. C. C.	$4.076 \pm .004$	$19.21 \pm .06$	$19.27 - 19.32$
	9	99.999		$4.064 \pm .004$	$19.37 \pm .06$	
Pb	4	99.96	F. C. C.	$4.920 \pm .005$	$11.48 \pm .03$	$11.341 - 11.347$

Sources

1. Aluminum Company of America
2. Reduced by hydrogen from "C. P." oxide
3. Vacuum fused electrolytic iron from Bureau of Standards

	Per Cent
C	.02
Mn	.001
P	.004
S	.017
Si	.021
	.06

4. Laboratory stock. Purity assumed to be as given
5. Baker Chemical Company
6. National Lamp Works, Lamp Development Laboratory
7. Prof. G. P. Baxter
8. Laboratory stock. Contains some Iridium.
9. San Francisco Mint

appear that, other experimental conditions being strictly the same, mechanical working of the metal causes slip along those planes in the crystal which have the maximum atomic population. It is a characteristic of the geometry of crystal structure that the planes of maximum atomic population are those which are furthest apart from each other. This means not only that the atoms in an individual plane are packed so closely together that they can hold to each other quite strongly, so that these individual planes of

[3] Zeit. f. Phys. 12, 58, 1922.

atoms are quite strong, but also that, because of the distance from any one of these planes to its nearest similar plane, the interlocking of atoms from plane to plane is relatively weak, so that each plane can glide over its neighbor.

In the face-centered cube, the 1 1 1 (octahedral) planes are those of greatest atomic population. There are four families of 1 1 1 planes symmetrically placed about 70½ degrees from each other. Each atom is symmetrically placed with respect to six other atoms in adjacent 1 1 1 planes, for there are three atoms which form an equilateral triangle in the plane immediately above, and three which form an equilateral triangle in the plane immediately below. This means that each atom is directly below the center of a triangle of atoms of the 1 1 1 plane next above it and is directly above the center of a triangle of atoms of the 1 1 1 plane next below it. This close packing prevents loss of cohesion during slip. The 1 0 0 planes have nearly as large an atomic population and are, therefore, almost as far apart from each other as the 1 1 1 planes. There are three families of 1 0 0 planes mutually 90 degrees to each other. Each atom in the 1 0 0 plane is equally spaced from four atoms in the adjacent plane above it and from four other atoms in the adjacent plane below. The face-centered cube is, therefore, well supplied with both primary and secondary slip planes, and since both of these families of planes have high orders of symmetry, a face-centered cube can hardly escape being ductile in almost any orientation. We may, therefore, expect that a rod or slab of polycrystalline face-centered cubic material will be ductile.

If the axial ratio of a hexagonal close-packed crystal is greater than 1.735 the 0 0 . 1 planes are the planes of greatest atomic population and should, therefore, be the planes of primary slip. This is the case with zinc, whose axial ratio is 1.86. Each atom in an 0 0 . 1 plane is equally spaced from three atoms in the two adjacent planes much as in the case of the face-centered cube. But the 0 0 . 1 planes are the basal planes of the hexagonal prisms. There is, therefore, only one direction through a zinc crystal which is the optimum direction for mechanical working. The planes of next highest atomic population in zinc are the 1 0 . 0 planes. These are the faces of the hexagonal prisms. There are three families of 1 0 . 0 planes, all parallel to the z-axis and all 120

degrees from each other. The atomic arrangement is not as favorable to slip without loss of cohesion as in the case of the 0 0 . 1 planes, for a given atom is equally spaced between four atoms in the adjacent plane on one side of it, and between only two atoms in the adjacent plane on the other side of it. There will be, therefore, greater loss in cohesion during slip along the 1 0 . 0 planes of zinc. We should expect that, contrary to the common opinion, slip along the 1 0 . 0 planes of zinc will show different characteristics from slip along the 0 0 . 1 planes. Instead of nearly every plane sliding over its neighbors we should expect the 1 0 . 0 planes to slip in blocks. If a single crystal of zinc is stretched beyond its elastic limit we should expect the etch figures to show block-slip along the 1 0 . 0 planes to a very much greater extent than along the 0 0 . 1 planes. In a private communication some time ago to Dr. S. L. Hoyt of this laboratory, O. E. Romig reported that he has found this to be actually the case. It is a pleasure to acknowledge Mr. Romig's permission to mention his experimental results which coincide so well with the theoretical deductions. It may be predicted that a similar study of the etch-figures of strained single crystals of face-centered cubic crystals will show that the etch-figures come mainly from the 1 0 0 and 1 1 0 planes.

If the axial ratio of a hexagonal close-packed crystal is less than 1.735 (as is the case with magnesium) the atomic population of the 1 0 . 0 planes will be higher than that of the 0 0 . 1 planes. Primary slip will, therefore, occur along the 1 0 . 0 planes. Since there are three families of 1 0 . 0 planes polycrystalline magnesium should be a little more ductile than zinc. Because of the unfavorable arrangement of atoms in the 1 0 . 0 planes of the hexagonal close-packed lattice, and since it has only three families of planes for primary slip and one for secondary slip, magnesium should be much less ductile than face-centered cubic metals like copper or aluminum, which have a favorable arrangement of atoms, and four families of planes for primary slip, and three for secondary slip. These conclusions are in accord with the results of practical experience.

In this connection cobalt is of peculiar interest. Pure cobalt is of only moderate ductility, while cobalt containing traces of

impurities is fairly ductile. Hull[4] showed that pure cobalt may contain some face-centered cubic crystals, but that it usually crystallizes in a hexagonal close-packed lattice. Traces of impurities always make cobalt take the face-centered cubic structure, thus giving a rational explanation of the ductility of impure cobalt.

A consideration of the body-centered cubic lattice shows it to be an inherently non-ductile structure. The planes of highest atomic population, and, therefore, those which are furthest apart, are the 1 1 0 planes. The atomic arrangement is such that each atom in a 1 1 0 plane is equally spaced from two atoms in the adjacent plane above it and from two other atoms in the adjacent plane below it. This means that slip along the 1 1 0 planes is necessarily accompanied by very great loss in cohesion. The crystal will tend to crack during mechanical working. The planes of next highest atomic population are the 1 0 0 planes. The atomic arrangement is here more favorable to slip, for each atom is equally spaced between four atoms on each side of it, but it is of little use to have planes of secondary slip with good cohesion if cracking occurs along the planes of primary slip. It would appear then that a body-centered cubic crystal would have to be supported during mechanical working, so that when slip occurs along the 1 1 0 planes the externally applied supporting pressure may prevent separation of the planes and thus may prevent the cracking of the crystal. This is exactly what is done in practice in the mechanical working of tungsten. The swaging hammers which are used to produce the deformation of the metal are so shaped as to provide mechanical support over as large a portion of the worked area as possible at each stroke. The hammers are rotated about the axis of the rod which is being worked, so that no two successive blows leave the same crystal planes without support. Even with this precaution it is necessary to limit the amount of reduction of the specimen per pass, so that cracking may not occur at the small portion of the specimen which is unsupported at any one stroke. The outstanding exception to all this is iron. Iron is body-centered cubic, and yet it is reasonably ductile. But this is not the only way in which iron is an exceptional metal. Its magnetic properties are such as to give rise to the term "ferro-magnetic." It is the only metal which, when sufficiently

[4] Physical Review *17*, 571, (1921).

heated, changes from a body-centered to a face-centered cubic lattice. It is quite likely that the exceptional behavior of iron during mechanical working is tied up in some way with the underlying causes of its other exceptional properties.

SOLID SOLUTIONS

When the atoms of metal B occupy positions in the crystals of metal A, then B is said to be in *solid solution* in A, and the atoms of B are called "stranger atoms." It was shown independently by E. C. Bain[5] and by W. Rosenhain[6] that in many cases the atoms of B merely replace atoms of A in the crystal lattice. This is to be expected when A is face-centered cubic. If A is body-centered cubic there is one other possibility,—the atoms of B may fit into the natural voids which exist in the body-centered cubic structure. Westgren and Phragmen[7] have shown from density considerations that this is actually the case when carbon is in solid solution in alpha (body-centered) iron.

Recent work by the writer throws considerable light on the mechanism of solid solutions. The aluminum atom is slightly smaller than the silver atom, but when aluminum is dissolved in solid solution in silver it stretches the silver lattice. Similarly tin stretches the silver lattice and silicon stretches the copper lattice. In all these cases it is believed that the "stranger atoms" replace atoms of the solvent metal in the crystal lattice. From the fact that the "stranger atoms" in each of the three cases mentioned above are smaller in size than the atoms of the solvent metal, no such stretching would be expected. If this is so, it is evident that the dissolved metal can not be present as atoms. A very simple explanation of the observed facts has been found, which will be more readily understood by first reviewing briefly the physical state of the two chemical elements in an ionic salt, such as NaCl (sodium chloride).

An atom is supposed, by physicists and chemists, to consist of a nucleus of positive electricity, surrounded by negatively charged electrons. Since the number of electrons is equal to the

[5]*Chemical and Metallurgical Engineering,* Oct. 5, p. 663, (1921).

[6]*Proceedings* of Royal Society, A, *99,* 196, (1921).

[7]Quoted by "H. C H. C.," Nature, July 19, 1924.

number of positive charges on the nucleus, the atom as a whole
is electrically neutral. The number of electrons which are sta-
tioned around the nucleus, and their configuration in space are
supposed to give rise to all the chemical and most of the physical
properties of the atom. For instance, an atom of chlorine is
supposed to have 17 positive charges on its nucleus. The simplest
way of grouping the 17 negative electrons to account for the
known chemical properties of chlorine is as follows:—2 near the
nucleus which form what is known as the "K shell,"—8 at the
corners of an imaginary cube to form the "L shell," which
completely boxes in the nucleus and the K shell,—7 arranged in
some manner (for instance, at 7 of the 8 corners of a still larger
imaginary cube) surrounding the L shell—these form the "M
shell." This picture may be and usually is made more compli-
cated in various ways to account for all the known physical and
chemical data, but it will be sufficient for our present purpose to
confine ourselves to the simple picture outlined above. It is
assumed that just as the L shell is complete when it contains 8
electrons, in the same way the M shell would be "complete," and,
therefore, chemically stable, if it had 8 electrons. This is sup-
posed to be the case in the atoms of the inert gases,—for instance,
argon has a nuclear charge of 18, and has not only 2 electrons in
its K shell and 8 in its L shell, but also 8 in its M shell. In like
manner, the inert gas neon, with a nuclear charge of 10, has 2
electrons in its K shell and 8 in its L shell. Sodium has a
nuclear charge of 11. It is supposed to have complete K and L
shells, and the 11th electron is the only one in the M shell. This
single electron is the valence electron of sodium. It is because
sodium tries to get rid of this electron by giving it away to some
other atom that sodium has a valence of one. But if the sodium
atom succeeds in giving up this valence electron to an atom of
chlorine, so as to form sodium chloride, it is no longer a neutral
atom, for it has 11 positive charges on its nucleus and only 10
negative electrons outside the nucleus. It has a net positive
charge of one, and has become a sodium ion, Na^+.

Just as the sodium atom tends to lose its valence electron in
order to have a complete shell of electrons for its outer boundary,
so a chlorine atom tends to gain an extra electron in order to
have a complete outside shell. In so doing it becomes a Cl^- ion,

for it now has one more negative electron than it has positive charges on its nucleus. Although the attractive force of the nucleus has been unaltered, the mutual repulsion of the electrons for each other has been increased by the presence of the extra electron, so that the chlorine atom must swell in size in becoming a Cl⁻ ion. The writer's value for the size of the Cl⁻ ion,[8] when compared with R. W. Wyckoff's for the size of the Cl atom,[9] shows that this swelling is very large,—the volume is increased over 300 per cent.

Just as the atom of the electronegative element chlorine swells in changing to a Cl⁻ ion, so an atom of the electropositive element sodium must shrink in losing its valence electron to form Na⁺. In the case of sodium, this shrinkage may be easily detected by X-ray crystal methods, which we can not go into deeply at this time. It will be sufficient to say that the volume of an atom is determined in terms of the distance of closest approach of atomic centers in the crystal. It has been shown by J. J. Thomson[10] that, using the simple picture of atomic architecture given above, the properties of the alkali metals, such as sodium, may be satisfactorily accounted for by assuming that the valence electrons lie along certain of the body-diagonals of the unit body-centered cube. But this is the direction in which measurements must be made to determine the distance of closest approach of atomic centers. In other words, the dimensions of a sodium atom, measured in this way, include the dimensions of its outmost complete shell, plus the effect of the valence electron on the distance of closest approach of atoms.

The distance of closest approach of atomic centers of face-centered cubic metals (such as copper and silver) is measured along the face diagonal of the unit cube. Thomson has shown that the valence electrons of monovalent face-centered cubic elements do not lie along the face-diagonal, but may be regarded as lying in little pockets at the centers of tetrahedra formed by the atoms adjacent to each corner of the unit cube[11] (see Fig. 5).

[8]*Physical Review,* 22, 211, (1923).

[9]*Proceedings* of National Academy of Science, 9, 33, (1923).

[10]"The Electron in Chemistry," published by the Franklin Institute. See also *Journal* Franklin Institute, *197*, 439, (1924).

[11]If the simple picture of atomic architecture is complicated by considering the electrons to move, the wording of the above becomes more complicated but the end result, in so far as it pertains to the point at hand, is the same.

It is evident that "atomic volumes" of metals like copper and silver determined in this way are but little affected by the valence electron.   Such volumes represent more nearly the volumes of the ions than of the atoms.   We should, therefore, expect that, in changing from the atomic to the ionic condition, copper and silver would show very much less apparent shrinkage than did sodium.

Now, in each of the solid solutions mentioned above, aluminum in silver, tin in silver and silicon in copper, the "stranger atoms" belong to a more electronegative metal than the "solvent" metal, as indicated by their positions in the Periodic Table.   They are the only three cases known where the atoms of the more electronegative polyvalent metal are smaller than the atoms of the electro-positive monovalent metal.   It is, therefore, reasonable to picture the increase in size of the "strangers" in the solid solutions mentioned above, as caused by a transfer of valence electrons to the electronegative "stranger" atoms from the regions near the adjacent atoms of the electropositive solvent metal.   If a single additional electron can make the volume of chlorine increase three-fold, one can hardly set a limit *a priori* to the swelling of aluminum (which would require five electrons to complete its outmost shell) or of silicon or tin (which would each require four).   This gives us a picture of solid solution which is at least as much chemical as physical in its make-up, for it makes us regard solid solution as being really a loose kind of ionic chemical combination.   We are tempted to make the generalization that in any solid solution, the atoms of the more electronegative element tend to steal electrons from the more electropositive element.   Any solid solution, from this viewpoint, falls short of being a true ionic chemical compound in two respects,—(1) the law of definite proportions is not obeyed except when we limit ourselves to the atoms immediately adjacent to the "stranger atoms," and (2) the positive nuclear charge at the center of the "stranger atoms" may not be, and usually is not, strong enough to hold as many additional electrons as existing chemical theory would require.

This viewpoint on solid solutions gives a rational explanation of the fact that solid solutions have lower heat and electrical conductivities than pure metals, for some of the valence electrons,

which are primarily responsible for conduction, are tied up to the more electronegative metal, and are, therefore, not available for conduction. Further confirmation may be found in the following. One would expect from the theory outlined above that when an intermetallic compound is formed, it should be found upon X-ray analysis to be ionic in its structure. E. A. Owen and G. D. Preston[12] have given strong X-ray evidence that the compounds $CuAl$ and $CuAl_2$ are not composed of neutral atoms, but that they "share electrons." Their data all seem to be consistent with the viewpoint that these compounds are indeed ionic.

SUMMARY

The method most in use in this country for the analysis of the crystal structure of metals has been outlined. In order to illustrate the value of crystal analysis as a tool in the theory of metallurgy and metallography, two illustrations have been given;—one showing how the arrangement of atoms in metals gives a rational explanation of their relative ductilities; the other showing how the parameters of the crystal lattices in solid solutions give a rational picture of the mechanism of solid solution.

[12]*Proceedings* of Physical Society, London, 36, 14, (1923).

CORRELATION OF ENDURANCE PROPERTIES OF METALS

By D. J. McAdam, Jr.

Summary of Paper[1]

THE RATIO of the rotating bend endurance limit to the tensile strength of a metal has been called the "endurance ratio"[2] or, more specifically, the "bend-tension static endurance ration."[3] Investigations of many kinds of steel have shown that this ratio varies from about 0.35 to 0.55; the average is about 0.50. When it had been found that the "endurance limit" of steel is approximately proportional to the ultimate tensile or torsional strength, and does not depend on ductility, it seemed reasonable to expect that the endurance limit of a non-ferrous metal would be found to depend only on the strength of the metal, and that the static endurance ratio for a non-ferrous metal would be found approximately equal to the static endurance ratio for steel.

Investigation of the endurance properties of non-ferrous metals had not progressed far, however, before it became evident that the static endurance ratio for a non-ferrous metal is less than the ratio for steel. For many non-ferrous metals, this ratio is less than half that for steel.

The surprising differences between the endurance ratios of various kinds of metal led to an investigation at the U. S. Naval Engineering Experiment Station to discover, if possible, the explanation. To determine whether these great differences between

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[1]Paper to be presented by permission of the Secretary of the Navy.

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[2]D. J. McAdam, Jr., "Endurance Properties of Steel: Their Relation to Other Physical Properties and to Chemical Composition," *Proceedings*, A. S. T. M., Vol. 23, Part II (1923).

[3]D. J. McAdam, Jr., "Endurance Properties of Corrosion Resistant Steels." *Proceedings*, A. S. T. M., Vol. 24, Part II (1924).

Summary of a paper to be presented by Dr. D. J. McAdam, Jr., at the Sixth Annual Convention of the Society, Boston, September 22 to 26. The author is metallurgist, U. S. Naval Engineering Experiment Station, Annapolis, Maryland.

the endurance properties of ferrous and non-ferrous metals could be referred to some property revealed by a tension test, long tension specimens of many ferrous and non-ferrous metals were tested. From the results of these experiments, which will be described in detail elsewhere, calculations were made of the actual stresses in the metal at "necking" and at breaking. Ductility values also were calculated in various ways. These calculations all failed to reveal any connection between the tension properties and the wide differences in endurance properties of various kinds of metal. Nevertheless, it seeemd probable that these differences could be referred to some tensile property not yet considered.

The paper discusses various possible relationships between endurance and tensile, torsional and shearing properties. For many alloys, the alternating torsion endurance ratio was found to be approximately proportional to the modulus of elasticity. Exceptions were finally encountered, however, notably in the magnesium alloys which have a low modulus of elasticity with rather high endurance ratio. Annealed duralumin, as reported by other investigators, also has a rather high endurance ratio with low modulus of elasticity.

Approximate endurance limits have been determined at the Naval Experiment Station for nickel, monel metal, copper, duralumin, electron metal, muntz metal, manganese bronze, phosphor bronze and other bronzes and brasses. For these determinations tests have been made by the rotating cantilever method and by the alternating torsion method. In the alternating torsion tests, the accelerated fatigue method[4] has been used. Stress cycle graphs illustrating the endurance properties of these metals are included in the paper.

The endurance limits thus obtained have been compared with the tensile, torsional, and shearing properties of the metals. The following endurance ratios have been calculated and tabulated: Bend-tension static endurance ratio, torsion-shear static endurance ratio, torsion-tension endurance ratio.[5] The influence of composition and of heat-treatment on these ratios is discussed. The addition of some alloying elements to pure metals apparently increases the static strength without corresponding increase in the endurance

[4]D. J. McAdam, Jr., "Accelerated Fatigue Tests and some Endurance Properties of Metals," *Proceedings*, A. S. T. M., Vol. 24, Part II (1924).
[5]D. J. McAdam, Jr., "Endurance Properties of Corrosion Resistant Steels," *Proceedings*, A. S. T. M., Vol. 24, Part II (1924).

limit.   The addition of other alloying elements increases both static strength and endurance limits, and may even increase the static endurance ratio.   Heat-treatment of some alloys raises the static strength without appreciable increase in the endurance limit. For example, heat-treatment of muntz metal causes a decrease in the static endurance ratio approximately proportional to the increase in tensile strength.   According to results reported by other investigators heat-treatment has little effect on the endurance ratio of duralumin.   Investigation of the influence of chemical composition and heat-treatment on endurance properties of non-ferrous metals is being continued.

THE BALL INDENTATION HARDNESS TEST

By Samuel L. Hoyt

Abstract

Professor Eugen Meyer of the Materials Testing Laboratory at the Imperial School of Technology, Charlottenburg, first published the results of his extensive investigation of Brinell's ball indentation hardness test in 1908. In this he showed that the hardness of a metal cannot truly be represented by one figure, or, to express it another way, the resistance to penetration varies with the degree of penetration of the ball. This variation can be taken into account by the relationship $P = ad^n$, where P is the load in kilograms and d is the diameter of the impression, and a and n are constants of the material under test. By this token we can compare two metals for penetration hardness only when we know either the whole course of the hardness curve or the material constants a and n. The two metals can then be compared either at constant load or at constant diameter of impression, for any degree of loading, by using the true mean pressure, p_m. It is equal to

$$\frac{P}{\frac{\pi d^2}{4}}$$

The inadequacy and inaccuracy of Brinell's hardness number were also shown.

In the present paper, Meyer's analysis is discussed somewhat at length to throw light on our present methods of hardness testing.

Introduction

THE PURPOSE of this paper is to present a rational analysis of the ball indentation test, and to show the manner in which such an analysis can be applied to certain fundamental problems in hardness testing.

We have all been aware of certain incongruities which come

up in hardness testing, but most of us have, like the writer, possibly dismissed them after too brief consideration. In some work in which the author has been engaged during the past two years, he has felt the desirability of obtaining a more complete interpretation of the ball indentation test, and it is with the feeling that this may be of interest to others that these results are recorded here. The key to this analysis is given by the work of Meyer and his assistant, Kürth, to whom we are deeply indebted for the pioneer work in this field.

Some Fundamental Conceptions

In the field of hardness testing we are primarily interested in the following points:

1. Definitions of hardness
2. Methods of determining hardness
3. Determining the hardness of various materials
4. Theories of hardness

It is with the first two points that we shall be concerned here.

In order to define the scope of this work, it will be well, first of all, to consider certain fundamental conceptions of the property of hardness. We may well say that our simplest conception of a hard substance is that it is one which cannot be readily scratched. This at once classifies such metals as lead, aluminum, and tin, as soft, and quenched high-carbon steel, carbides, nitrides, etc., as hard substances. To go further, however, we must distinguish between *particle hardness* and *mass hardness*. For instance, an alundum tube may be easily worn away by a file, but the file, in turn, will be scratched by the particles of alumina which are worn away. The mass hardness of the file is greater than that of the alundum tube, but the particle hardness of the tube is greater than that of the file.

The differences between particle hardness and mass hardness should be considered in connection with the effect of grain size on the hardness. It is inconceivable that a grain of copper, for example, that is a cubic centimeter in size is necessarily any harder or any softer than one a cubic millimeter in size. In massive

form, however, from the effect of the bonds between the grains of pure metals, it is quite conceivable that the mass hardness of fine-grained copper differs from that of coarse-grained copper. Again, in alloys composed of two constituents, the constituents may, and generally do, possess different particle hardness. The alloy as a whole has no particle hardness in our sense; instead, each constituent has its own particle hardness which does not vary with the alloy composition, but the mass hardness of the alloy, on the other hand, is a very definite thing—a property that will vary with the composition according to a definite law.

Scratching implies that the metal is deformed beyond its elastic limit; in brittle materials, by an amount sufficient to produce cleavage, and in ductile materials, sufficient to produce plastic flow. Scratching further implies (1) local rather than general application of the load, which in turn implies (a) local deformation with (b) restricted flow of metal during deformation; (2) that the load is applied by or through a substance which is harder than the metal under test; and (3) that deformation is confined to the metal under test.

It is exactly these conditions which distinguish the hardness test from such a test as the tension test, even though in the latter, the load applied produces plastic flow. The "resistance to plastic deformation" on this account, cannot give an exact or useful determination of the hardness. For example, cast iron, in the compression test, takes a load of around 3800 kilograms per square centimeter, but in a hardness test, the load may run up to about 18,000 kilograms per square centimeter.

The ball test meets these conditions with sufficient exactitude so that it can be regarded as a true hardness test in the light of our definition. The merit of Meyer's analysis is that it gives a more fundamental and useful conception of the property than the definition does. In the case of brittle materials, the ball test would be conducted according to the Auerbach test, which need not concern us here. The plastic and ductile metals would be tested according to the ball indentation test.

The Ball Indentation or Brinell Test

In the ball indentation test or Brinell test, the steel ball is pressed into a surface of the metal under test by the application

of the load. The ball should not undergo (material) deformation during the test. Here the pressure on the metal is exerted from nearly all sides; from the top by the ball, and from below by the metal itself, and the flow of metal is correspondingly restricted.
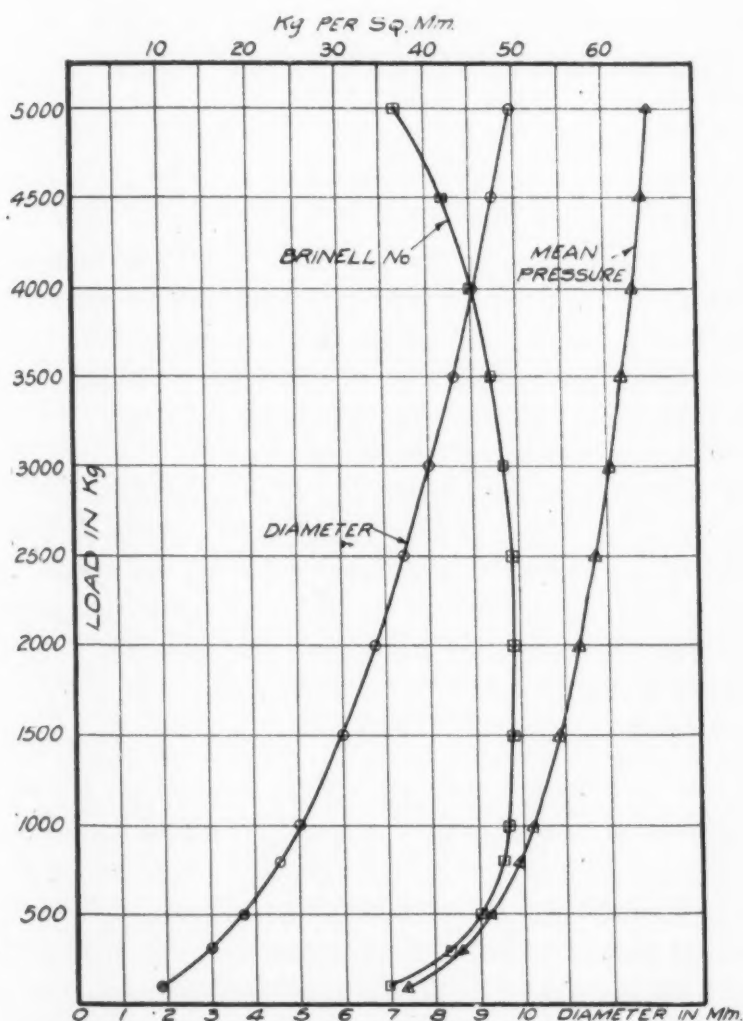

Fig. 1—Brinell Tests of Annealed Copper.

The conditions which obtain during the course of a test and the relationship between the load applied and the resistance offered by the metal may be pictured as in Fig. 1. The metal used for this test was annealed copper.

The first curve shows how the diameter[1] of the impression increases as the load on the ball is increased. At first glance, it will be seen that no one point on this curve can be used to represent the relation between the load and the resistance of the metal to penetration. Neither can any one figure be used to represent the course of this curve, so we should not expect to be able to represent the "hardness" by any one figure. On the other hand, Meyer noted that this curve, or relationship, can be expressed by the equation:

$$P = ad^n \qquad (1)$$

where P is the load on the ball and d is the diameter of the impression. This equation has two constants, a and n, showing positively that no one figure can be used to give a true picture of the resistance of copper to penetration. By the same token, two metals could not be compared as to their "resistance to penetration" by means of two figures.

The Brinell hardness number comes at once to mind in this connection as two metals are frequently compared as to "hardness" by means of Brinell numbers. The Brinell number has been plotted as the second curve in Fig. 1. The Brinell hardness number was calculated for different loads according to the usual formula, in which D is the ball diameter and d is the diameter of the impression:

$$H = \frac{P}{\pi D \left[\frac{D}{2} - \sqrt{\left(\frac{D}{2}\right)^2 - \left(\frac{d}{2}\right)^2} \right]} \qquad (2)$$

The Brinell number passes through a maximum as the pressure is increased and then falls off at higher loads in a manner which is not at all consistent with the true resistance of the metal to penetration and which reflects, rather, the geometry of spherical surfaces. To obviate the disadvantage of using such a number as the Brinell number, and to give a figure which represents a true physical conception, Meyer used the mean pressure which is supported by the metal. This he designated as p_m. The mean

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[1] In the Brinell test, the load is allowed to remain on for thirty seconds. The test recorded in Fig. 1 differs from the Brinell test in that the load was left on the ball until it came to rest and the diameters are correspondingly greater.

pressure was derived by dividing the load by the projected area of the impression, as follows:

$$p_m = \frac{P}{\frac{\pi d^2}{4}} \qquad (3)$$

The mean pressure curve is likewise plotted in Fig. 1 as the third curve. This curve varies in a definite and regular manner with the load, and may be taken as truly representing the resistance of the metal to penetration at any point. It is necessary here, of course, to allow the ball and the sample to come to equilibrium, or to rest, under the load, before the readings can be taken. For example, a load of 3000 kilograms requires about 15 minutes to come to rest in annealed copper.

Equation (1), being an exponential equation, may be rewritten,

$$\log P = \log a + n \log d \qquad (4)$$

The plot of this equation appears as in Fig. 2, which represents the loads in kilograms and the corresponding impression diameters, in millimeters, plotted on log-log paper.

For laying down such a curve the author has been determining at least four points. The constants a and n can then be obtained directly from the plot, or arithmetically by substituting the P and d values in two equations of the form of equation (4). From equation (4), it may be seen that when $d=1$, then $P=a$, or, in other words, that the constant a is the load in kilograms required to produce the impression diameter of one millimeter. It is given in kilograms per square millimeter. It may also be seen that the constant n is the slope of the straight line in Fig. 2, and, therefore, that it shows how the diameter increases with the load after the initial impression has been produced. In other words, a gives the resistance of the metal to initial penetration and n measures the effect of the deformation on the hardness of the metal. We may also say that n gives a measure of the capacity of the metal to be work-hardened. A metal which has this property will show a high n value (say 2.3 to 2.5), while other metals, such as lead, will have an n value around 2.

Meyer found, on examining 18 different metals of widely varying mechanical properties, that the a and n values vary

indiscriminately from metal to metal. The hardness at a given point may be due to a high a value and a low n value, or to a lower a value and a higher n value. While these circumstances
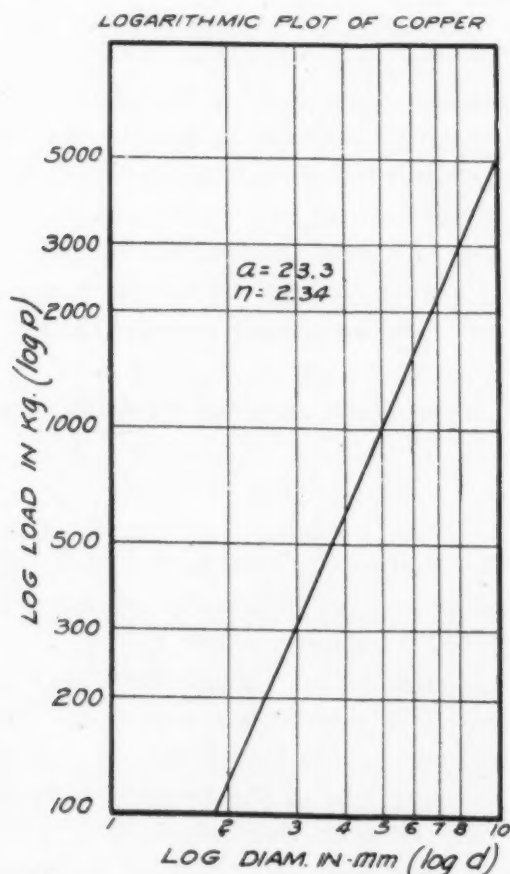
Fig. 2—Logarithmic Plot of Copper.

do not alter the hardness value at this point, it is clear that the whole picture of the hardness of the metal cannot be represented by any one number, not even by p_m, and still less by the Brinell number.[2] The very act of measuring penetration hardness affects the hardness of the metal and this by an amount which varies with the different metals and with the condition of a given metal. Therefore to get an accurate idea of the hardness of metals or of the hardness relations between the metals, the fundamental constants of the metals, such as a and n, must be known. In other words, the hardness of metals should be considered on the basis

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[2]This applies also to the maximum hardness number, H_{max} of Waizenegger and of O'Neill, which are discussed later.

of the whole curve and not on the basis of any one arbitrarily selected point.

It is hoped that the reasoning to this point will have brought out the facts (1) that the hardness of a metal is a variable quantity depending upon the penetration and that, therefore, the hardness relations of metals must be represented by at least two figures, such as the constants a and n, and (2) the hardness at any specific point should be given by the mean pressure which is being sustained by the metal at that degree of deformation.

EFFECT OF THE BALL DIAMETER, "D"

In the standard Brinell test, the ball diameter used is 10 millimeters, while in modifications of this test, entitled the "baby" Brinell test for use on thin materials, a much smaller ball is used. Meyer has shown that equal hardness numbers, p_m, are obtained when using balls of different diameters, provided the loads used produce geometrically similar impressions. Geometrically similar impressions have equal impression angles Φ, where Φ is the solid angle between the center of the ball, when in place in the impression, and the rim of the impression. Φ is obtained from the relationship,

$$d = D \sin\left(\frac{\Phi}{2}\right)$$

$$\text{Now } p_m = \frac{P}{\frac{\pi}{4} d^2} \text{ and, hence, } = \frac{P}{\frac{\pi}{4} D^2 \sin^2\left(\frac{\Phi}{2}\right)}$$

Therefore, if equal impression angles and equal mean pressures are to be obtained, the expression $\frac{P}{D^2}$ must remain constant. This is true when the following relationship is observed: $P_1 : P_2 :: D_1^2 : D_2^2$. If we use some other ball diameter than 10 millimeters, in order to get similar hardness numbers, the load used with the new ball should be

$$P_2 = \frac{3000 \times D_2^2}{100} = 30 \, D_2^2$$

Meyer tested this point with copper, using ball diameters of 5, 10 and 15 millimeters, and found it to hold satisfactorily. The

same was found to be true with mild steel and ball diameters of 7.5, 10 and 20 millimeters and also for gray and white cast iron. The error involved by neglecting this relationship may be shown by the results of Hanriot, which are given in Table I.

Table I

	Brinell Hardness Number	
	P=1000 kg., D=10 mm.,	P=30 kg., D=3 mm.
8% Aluminum Bronze	95	67
Nickel	80	60
Silver-Copper Alloy (83.5% Ag.)	68	55

On the basis of Meyer's work, Hanriot should have used a pressure of 90 kilograms instead of 30 kilograms, to get results with his 3-millimeter ball, which would have been comparable with those obtained with a 10-millimeter ball and a load of 1000 kilograms. What Hanriot actually did was to get the hardness numbers at two different points on the P : d curve, and quite as one would expect, they were not equal. Of course he used Brinell hardness numbers, but we may take them as illustrating the necessity of using the correct relationship between pressures and ball diameters.

The ball diameter has another effect. The constant a falls with increase in D for all metals which have an n value that is greater than 2. This relationship is given by

$$a_1 D_1^{n-2} = a_2 D_2^{n-2} = a D^{n-2} \tag{5}$$

which is constant for each metal, independent of D, expressed in kilograms per square millimeter. The change in a with D increases as n increases. As for the effect of D on n, we know that $P = a_1 d^{n_1}$ and $P = a_2 d^{n_2}$ for two different ball diameters. The mean pressure for the first case is

$$p_m = \frac{P}{\frac{\pi}{4} d^2} = \frac{4 a_1}{\pi} d_1^{n-2} = \frac{4 a_1}{\pi} D_1^{n_1-2} \left(\sin \frac{\Phi}{2} \right)^{n_1-2}$$

where Φ is the impression angle. If the mean pressures for the two balls are to be the same for the same impression angles, then

$$a_1 D_1^{n_1-2}\left(\sin\frac{\phi}{2}\right)^{n_1-2} = a_2 D_2^{n_2-2}\left(\sin\frac{\phi}{2}\right)^{n_2-2}$$

for any impression angle. This can be true only if $n_1=n_2$, so we may say that the constant n is independent of the ball diameter.

The Law $P=ad^n$ and p_m

From this law we get the following relationships for the hardness p_m:

$$p_m = \frac{P}{\frac{\pi}{4}d^2} = \frac{4a}{\pi}d^{n-2} \qquad (6)$$

expressed in terms of the impression diameter, and

$$p_m = \frac{P}{\frac{\pi}{4}\left(\frac{P}{a}\right)^{\frac{2}{n}}} = \frac{4}{\pi}\,a^{\frac{2}{n}}\,P^{\frac{n-2}{n}} \qquad (7)$$

expressed in terms of the load.

If $n=2$, which is true only for severely cold-worked metals, then the hardness is independent of the load used in the test and is always equal to $\frac{4a}{\pi}$ We also find, from the relation $a_2=a_1\left(\frac{D_1}{D_2}\right)^{n-2}$ that the hardness is also independent of the ball diameter D, for if $n=2$, the a value remains constant. Such a metal resists penetration with the mean value of $\frac{4a}{\pi}$ kilograms per square millimeter, irrespective of the diameter of the ball and the load used. Cold-worked copper approaches this state very closely. We should note, however, that even though $n=2$, the Brinell hardness number will actually vary with the load. This case is only an ideal, or limiting case, for metals in their annealed condition, so we may say in general, that the hardness varies with the penetration.[3]

The increase in hardness with penetration is greater the higher the n value, and actually varies from metal to metal. To get an idea of the magnitude of this effect, let us take a simple case, and one that is representative of ordinary practice. With $n=2.3$, the metal will show 51.6 per cent greater hardness (p_m) when tested at $d=4$, than when tested at $d=1$; but if tested at $d=6$, the

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[3]In the case of lead, n is less than 2, according to Meyer, so that the hardness would decrease with the penetration. It will be shown later that n varies with the time of application of the load.

hardness increases only 12.9 per cent more. If tested at $P=2000$ kilograms, the hardness is 20 per cent greater than when tested at $P=500$ kilograms. By testing at $P=3000$ kilograms, the hardness value is increased 3.3 per cent more.

If all metals had equal n values, comparison of different metals as to hardness would be greatly simplified. In these circumstances it would be necessary simply to test at constant P or constant d. Our present practice of using a constant load of 3000 kilograms would be sound. The hardness of the two metals at constant d would be to each other as

$$\frac{p_{m1}}{p_{m2}} = \frac{\frac{4}{\pi} a_1 d^{n-2}}{\frac{4}{\pi} a_2 d^{n-2}} = \frac{a_1}{a_2} \tag{8}$$

The corresponding loads would be $P_1 = a_1 d^n$ and $P_2 = a_2 d^n$.

We would have $\dfrac{P_1}{P_2} = \dfrac{a_1}{a_2} = \dfrac{p_{m1}}{p_{m2}}$, and the hardness ratio would be independent of the diameter of impression selected.

Based on equal loads, the comparison of the two metals as to hardness would be as follows:

$$\frac{p_{m_1}}{p_{m_2}} = \frac{\frac{4}{\pi} a_1^{\frac{2}{n}} P^{\frac{n-2}{n}}}{\frac{4}{\pi} a_2^{\frac{2}{n}} P^{\frac{n-2}{n}}} = \left(\frac{a_1}{a_2}\right)^{\frac{2}{n}} \tag{9}$$

The comparison is again independent of the load selected, and it also follows that the comparison is independent of the ball diameter, assuming only that the same ball diameter be used for each metal.

To illustrate this, let us take a soft metal (aluminum alloy) with $a_1=39$ and a hard metal (nickel steel) with $a_2=186$, for each of which $n=2.30$. We can say that the second metal is $\frac{186}{39} = 4.8$ times as hard as the first, as 4.8 times as much pressure is required to produce a given impression diameter with the second as with the first. Or we can say that the second metal is $\left(\frac{186}{39}\right)^{\frac{2}{2.3}} = 3.9$ times as hard as the first. At the same load, the area of the impression of the first is 3.9 times that of the second. Either procedure offers a precise method of comparing the hardness of

the two metals, but of course, we get two different values of the hardness ratio, depending on the basis of the comparison. However, if we were to get the Brinell number of the softer metal at 500 kilograms and of the harder one at 3000 kilograms, the hardness ratio would be different from that given here and would not have the same precise physical significance.

In general, different metals have different n values, as well as different a values, and our comparison becomes more complicated. Thus, if we compare two metals on the basis of equal d's, we have

$$\frac{p_{m_1}}{p_{m_2}} = \frac{P_1}{P_2} = \frac{a_1\, d^{n_1}}{a_1\, d^{n_2}} = \frac{a_1}{a_2}\, d^{n_1 - n_2} \qquad (10)$$

as the relation between the pressures. This value varies with the choice of d and the more, the greater the difference $n_1 - n_2$ is. On the basis of equal pressures, we have

$$\frac{p_{m_1}}{p_{m_2}} = \frac{\dfrac{P}{\dfrac{\pi d_1^2}{4}}}{\dfrac{P}{\dfrac{\pi d_2^2}{4}}} = \frac{d_2^2}{d_1^2} = \frac{\dfrac{4a_1^{\frac{2}{n_1}}}{\pi} P^{\frac{n_1-2}{n_1}}}{\dfrac{4a_2^{\frac{2}{n_2}}}{\pi} P^{\frac{n_2-2}{n_2}}} = \frac{a_1^{\frac{2}{n_1}}}{a_2^{\frac{2}{n_2}}} P^{\frac{2}{n_1 \cdot n_2}(n_1 - n_2)} \qquad (11)$$

To illustrate with $n_1 = 2.3$ and $n_2 = 2.1$, if the hardness ratio for these metals at P=500 kilograms is unity, then if tested at 4000 kilograms, the hardness ratio would be 1.188. Further, if the metals have a hardness ratio at d=1 millimeter of unity, the ratio at d=4 millimeters would be 1.317 and at d=7 millimeters it would be 1.475.

To illustrate these points further, Meyer has plotted his hardness determinations, using p_m, on the basis of d=1 and of P=3000 kilograms. In this way, he shows that the latter gives a different seriation of the metals than the former and that the actual hardness figures differ widely from each other.

We may little wonder, in the light of these relationships, that hardness comparisons made with a load of 500 kilograms frequently differ from those which are made at higher pressures and that our hardness comparisons made on the basis of Brinell numbers are often confounding.

OTHER HARDNESS NUMBERS

Realizing the value of having a single number to express the

hardness of a metal, attempts have been made to utilize the Meyer exponential relationship for the purpose.

Waizenegger[4] has deduced a value as follows:

Referring to equation (5), we note that we may calculate a constant, which is independent of D, as follows:

$$A = a\, D^{n-2} \qquad (12)$$

The exponential equation then becomes:

$$P = \frac{A}{D^{n-2}}\, d^n \qquad (13)$$

By plotting values of the Brinell hardness against the corresponding loads, a curve is obtained which, in general, passes through a maximum, although some metals, such as steel, do not show the maximum up to 3000 kilograms (Meyer). The maximum value of this curve is proposed as a measure of the hardness and is called the maximum hardness number, H_{max}. By means of a series of equations, which may be secured from the original, he shows that:

$$H_{max} = A\, \frac{\left[\sqrt{\dfrac{n\,(n-2)}{n-1}} \right]^n}{\dfrac{\pi}{2}\left(\dfrac{n-2}{n-1}\right)} \qquad (14)$$

H_{max} depends only on A and n and holds over the same range as $P = a d^n$.

More recently O'Neill[5] has also suggested using the maximum Brinell number which he represents by

$$H_{max} = \frac{2a}{\pi} \cdot D^{n-2} \cdot \left\{ \frac{n(n-2)}{(n-1)^2} \right\}^{\frac{n-2}{2}} \qquad (15)$$

where H_{max} represents the maximum Brinell hardness number. The impression diameter at which this maximum comes will vary from metal to metal and varies with n. Meyer showed this as follows.[6] The change in the Brinell number may be written

[4]Zeit. Ver. deut. Ing., 1921, Vol. 65, p 824.

[5]*Journal* of the Iron and Steel Institute, No. 1, 1923.

[6]Ibid, p. 653.

$$\frac{dH}{dd} = \frac{d}{dd}\left(\frac{ad^n}{\frac{\pi D^2}{2} - \frac{\pi D}{2} \mid \overline{D^2-d^2}}\right)$$

To get the impression diameter at the maximum of this function, we equate to zero and then $d_o = \frac{D}{n-1}\sqrt{(n-2)n}$. If the ball diameter is 10 millimeters then we get the following values for d_o:

For $n=$	2	2.1	2.2	2.3	2.4
$d_o=$	0	4.17	5.53	6.39	7.00

Thus, if we compare two metals as to hardness which have different n values, the hardness numbers will correspond to different depths of penetration. So the use of H_{max} is doubly wrong, first because it has the defects of a Brinell hardness number and secondly because it does not correspond to a given load or to a given impression. Its numerical value depends, not simply upon the physical properties of the metal, but also upon the geometrical characteristics of spherical impressions.

EFFECT OF PLASTIC DEFORMATION

It is generally true that working a metal when it is well below its annealing temperature results in an increase in hardness and in tensile strength and in a decrease in ductility, using these terms with their usual meaning. Kürth[7], following Meyer, has brought out some interesting relationships between plastic deformations and the constants a and n.

With test bars of annealed copper and nickel he found the variation of a and n and the yield point, after successive elongations of the test bars in the tensile testing machine. Each time he stretched the bar, the yield point was raised, the *hardness* increased and the constants a and n were changed. In order that we may have a clear picture of the effects of this type of deformation, Kürth's results are reproduced in tabulated and diagrammatical form:—see Fig. 3 and Table II. It will be seen of course that the so-called increase in hardness of deformed metals is due to the increase in a. The other factor n acts in the direction of softening the metal, at the higher loads.

[7] Zeit. Ver. deut. Ing., 1908, Vol. 52, p. 1560.

We may see from this work that annealed metals have a greater capacity for being work-hardened than deformed metals. Numerically, this capacity is given by the constant n. In this type of

HARDNESS VS YIELD POINT OF STRAINED COPPER
(KÜRTH)
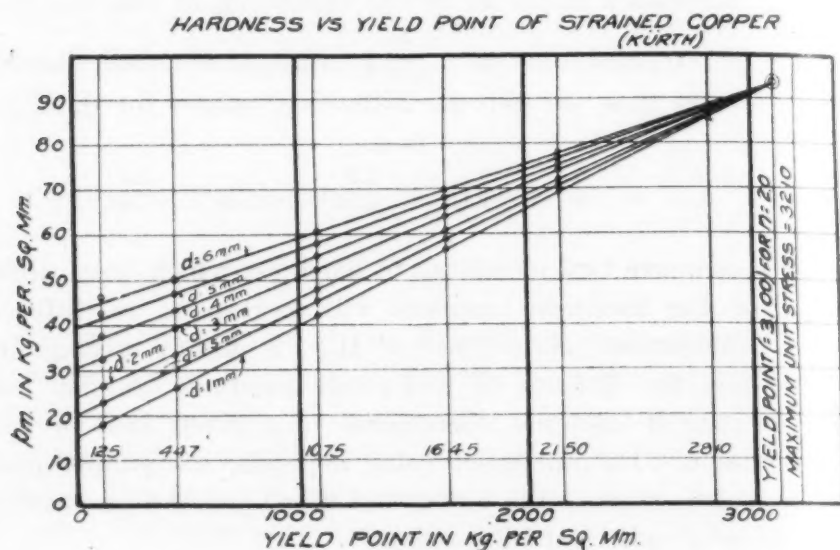
Per cent Elongation	0	1.5	5.5	11.3	20.0	39.5
Y. P. in kg. per sq. mm.	125	447	1075	1645	2150	2810
p_m for d=1 mm.	18.7	26.75	42.5	56.5	70.0	86.6
" 1.5 "	23.3	30.95	46.0	59.2	71.9	87.0
" 2.0 "	27.0	34.25	48.6	61.4	73.1	87.1
" 3.0 "	33.25	40.0	53.05	64.5	74.8	87.7
" 4.0 "	38.2	44.15	56.0	66.8	76.2	88.0
" 5.0 "	43.1	47.8	58.7	68.55	77.1	88.1
" 6.0 "	46.8	51.1	61.1	70.0	77.9	88.2

Fig. 3—Hardness Versus Yield Point of Strained Copper. (Kurth.)

·deformation (that is, by tensile pull), the constant n appears to approach the value 2 as a limit, and would probably have a value of 2 if the yield point were raised to the tensile strength.

Following this line of reasoning, Kürth plotted the hardness values (p_m) for different impression diameters against the yield points. He found that the hardness for a given d increased as a linear function of the yield point and that the hardness values for different d's fell on converging straight lines (see Fig. 3). This convergence is due to the decrease in n until finally, at n=2, the mean pressures are equal for all loads. Table II gives the variation in a and n with the stretching of the test bar, for both copper and nickel.

Table II

		Copper					
Per Cent Elongation	0	1.5	5.5	11.3	20.0	39.5	
a	14.7	21.0	33.4	44.4	55.0	68.0	
n	2.52	2.36	2.20	2.12	2.06	2.01	
		Nickel					
Per Cent Elongation	0	2	4.85	10	17.4	29.5	at Frac.
a	47.0	65.0	79.5	98.0	117.0	139.5	158.5
n	2.40	2.28	2.23	2.17	2.13	2.08	2.05

This line of reasoning enables one to calculate the yield point of the annealed metal. The yield point which is obtained gives a determination which is accurate and simple to make and applies to metal whose yield point is not at all defined, and which is hard to determine accurately. To do this, Kürth proposed obtaining the ratio of the change in yield point to the change in hardness, which is:

$$\frac{Y.\,P._2 - Y.\,P._1}{p_{m_2} - p_{m1}} = \frac{\lrcorner\, Y.\,P.}{\lrcorner\, p_m} = \text{Const.} \quad (16)$$

Substituting values for copper, using d=4 millimeters, which can be obtained from Fig. 3, we get, for example:

$$\frac{2150 - 447}{766.2 - 44.15} = 53.2 \text{ for } d=4 \text{ millimeters}$$

Then letting the yield point of annealed copper be x and using the hardness for annealed copper, we have

$$\frac{2150 - x}{766.2 - 38.2} = 53.2$$

Whereupon x=128 kilograms per square millimeter, which checks reasonably well with the value of 125 kilograms per square millimeter which he found.

We may also calculate the unit stress at rupture without breaking the bar, by calculating the yield point corresponding to n=2. This gives a figure which differs somewhat from the tensile strength as the former figure relates to the cross-sectional area at fracture and the latter to the original cross-sectional area. The figures so calculated agreed with the strengths found for copper and nickel within 3 to 4 per cent.

It is interesting to note that the yield point, while being definitely related to the hardness, cannot be taken as a measure of the hardness. As Kürth points out, it is the change in the two properties and not the absolute values of these properties which gives this relation.

Another interesting fact here is that if we test at a constant impression diameter, the ratio between the unit stress at fracture and the hardness is constant for a given n, at least for copper, nickel and iron. Other metals would probably also follow this relationship. It was found to hold very well from n=2.5 down to a value slightly greater than 2.0. As a corollary to this, it follows that the ratio of hardness to the unit stress at rupture varies continuously with variation in n. It should be noted specifically that this strength-hardness relationship is for worked metals and that it is between the maximum unit stress and the Meyer hardness number, p_m, geometrically similar impressions being used to determine the hardness. This is greatly different from a tensile strength—Brinell hardness number relationship.

The writer has noted, on determining a and n for copper bars which have been reduced by various amounts of cold-working, that a increases rapidly from about 20 to about 75, and that n decreases with equal rapidity from about 2.40 to around 2 or even a little below. Without going into an analysis of this work, we may see that the change in a and n due to cold working is about the same as Kürth found from tensile stretching. The increase in "hardness," which is commonly observed, is due to the increase in a. The constant n may be used to define the condition of strain of the metal and is a better figure for the purpose than any now commonly used.

EFFECT OF TEMPERATURE ON HARDNESS

Kürth[8] examined copper, nickel, silver, tin, zinc and steels at temperatures below and above room temperature. In the equation $P=ad^n$, the exponent n is a measure of the effect of P on the hardness, the higher n is, the more the hardness number varies with the depth of impression. It was thought that high temperatures, by producing an annealing or softening effect, would affect the hardening action of the indentation and so show an effect on

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[8]Zeit. Ver. deut. Ing., 1909, Vol. 53, p. 85.

the exponent n. This was not found to be the case. It was found
that copper at 500 degrees Cent. (932 degrees Fahr.) (i. e., above
the annealing temperature) showed the same hardening on in-
creased loading that was found at room temperature. In fact, n
was taken to remain constant for all the metals tested, provided
that the metals were in the annealed condition at the start. The
following figures for copper and silver are representative, see
Table III.

Table III

Copper

Temperature—Deg. C.	H or p_m at P=1000 Kg.	H or p_m at P=600 Kg.	a	n
18	44.8	40.6	14.7	2.52
250	34.4	30.7	10.6	2.52
464	. . .	22.0	6.95	2.52

Silver

18	34.5	31.7	13.3	2.39
200	31.7	29.6	12.2	2.39

If the metal at the start were cold-worked—that is if n were
approximately 2—a test at elevated temperatures would show n
increasing; the constant a, on the other hand, would decrease on
rise in temperature the same as with annealed metals, and it is due
to this fact that metals soften at high temperatures. In the case
of cold-worked metal, the hardness falls rapidly on passing through
the annealing range, and the exponent n reaches the value which
it has for the annealed metal.

Kürth states that the hardness of copper and the constant a
decreases as a linear function of the temperature between—83
degrees and 524 degrees Cent.[9] Copper appears to be exceptional
in this behavior as low temperatures generally affect the hardness
differently than the higher temperatures; more rapidly in the
case of zinc and less rapidly in the case of nickel. Some of
Kürth's data are given in Table IV.

On coming to zinc and tin, a different situation was found.
Ordinarily the metal under test comes to equilibrium with the load
in a brief time. Aluminum at a high temperature was the only
exception. Tin and zinc showed only slight tendency to cease
flowing under load. By carrying out determinations at certain
definite times of maintaining the load on the sample, the time

[9] At 523 degrees Cent. a=5.78 for copper.

effect was observed. Both a and n decrease with the time the load is left on. This effect is also noticeable with lead as Norbury has recently shown.[10]

Table IV

Hardness (p_m) of Nickel vs. Temperature

Temp. Deg. C.		−82	−40	+18	+80	+150	+200	+250
p_m in kg. per sq. mm. (1)		114.5	114.7	113.5	113.0	112.2	111.6	107.0
	Temp.	+336	+400	+450	+465	+500		
	p_m	100.0	95.7	91.0	87.2	84.0		

(1) p_m was determined for P=1500 Kg.

Hardness (p_m) of Aluminum vs. Temperature

Temp. Deg. C.	+18	+100	+150	+200	+240	+250
p_m in Kg. per sq. mm. (2)	37.1	32.2	27.7	21.8	17.7	16.4

(2) p_m was determined for P=400 Kg.

THE HARDNESS OF ANNEALED STEEL VERSUS CARBON CONTENT

Kürth determined the constants a and n for a graded series of annealed carbon steels containing under 0.4 per cent of Ni, Co, Cu, Al, Mn, Si, P and S. The iron was a very pure grade from Krupp's. The results are given in Table V.

Table V

Constants a and n of Annealed Steel (Kürth)

Carbon Content	a	n
Pure Iron	34.7	2.41
0.20%	52.5	2.35
0.39%	64.0	2.35
0.51%	81.0	2.30
0.75%	95.0	2.35

Wüst and Bardenheuer in their work on the hardness of steel have given impression diameters for various loads, and from them the author has calculated the a and n values for their steels. These are also plotted in Fig. 4. From these curves, we may assume that the increase in hardness on increase in carbon, is due to the increase in a. n appears to remain fairly constant.

From what we know of the behavior of quenched steel in the Brinell test, it is fair to assume that quenching increases the cou-

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[10]A. L. Norbury, *Transactions* Faraday Society, 1923, Vol. 19, Pt. 1. n fell from 2.35 to 1.94 as the time of maintaining the load increased from 2 to 1200 seconds. a remained constant at 23.

stant a very materially. Nothing is known at present, regarding
the effect of quenching on the constant n.

Kurth also determined the hardness of his steels at tempera-
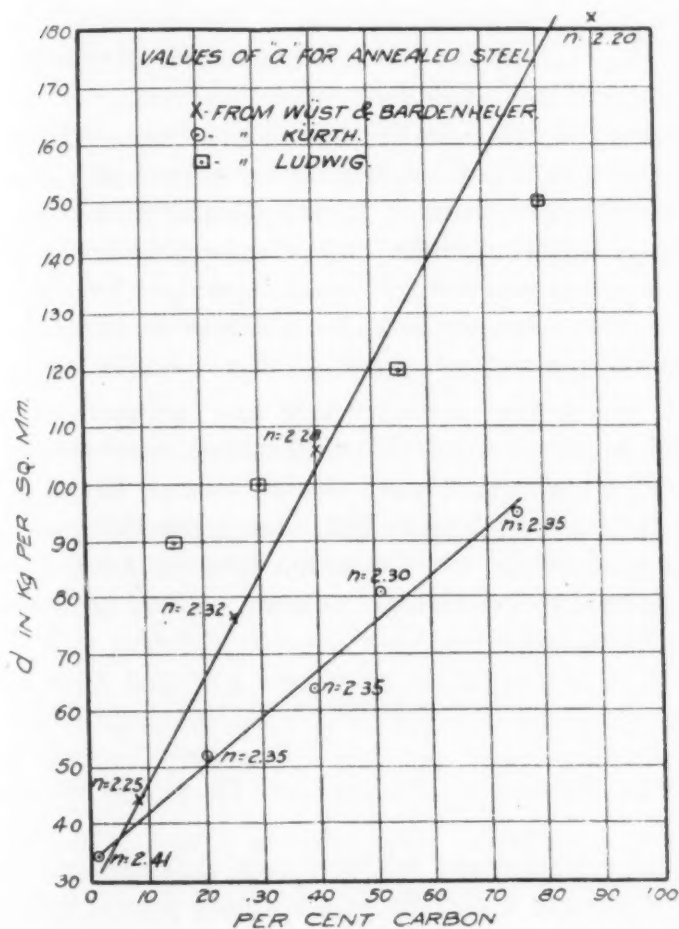tures ranging from —80 to +500 degrees Cent. The general effect

Fig 4—Values of "a" for Annealed Steel.

for the steels was as follows: The hardness fell gradually from
—80 degrees Cent. as the temperature increased to about 200 de-
grees Cent., the exact point increased slightly with the carbon
content. For the next 50 to 100 degrees Cent. the hardness in-
creased slightly and then fell off at a somewhat more rapid rate
as the temperature increased to 500 degrees Cent. The pure iron
showed an anomolous behavior, in that it showed a much more
marked maximum than the steels. the temperature being 200 de-

grees Cent. At the maximum the hardness was 119.2 as compared
to 84 at room temperature. The steel with 0.39 per cent carbon
ran only 125 at room temperature and 114 at 200 degrees Cent.
The steel with 0.20 per cent carbon was still softer at all tempera-
tures, by about 20 kilograms per square millimeter.

BALL HARDNESS AND SCLEROSCOPE HARDNESS

The height of rebound has not as yet been satisfactorily cor-
related to the results of the ball indentation test, although many
attempts have been made. These attempts have been empirical
in nature, or a sort of calibration of the one quantity against the
other for a given material. The relationship which holds for one
metal does not necessarily hold for another metal, so we cannot as
yet set up the general relationship.

O'Neill has shown[11] recently that his "ultimate hardness," or
the Brinell hardness at $d = 10$ millimeters, when plotted against
the scleroscope hardness, gives a smooth curve. The a values of his
materials varied from 5.53 to 342, except for the manganese steel
whose a is recorded as 453 and which does not come on the curve.
O'Neill relates the scleroscope number to the fundamental con-
stants by the equation

$$S^{1.44} = 0.806a \times 10^{n-2} \qquad (17)$$

MEYER HARDNESS NUMBER AND BRINELL'S NUMBER

In the preceding pages we have seen that Meyer's analysis of
the ball indentation test leads to a rational interpretation of both
the property and the test. The basis of this work lies in the
relationship $P = ad^n$ between the load and the diameter of impres-
sion and the use of the mean pressure, p_m, as the measure of the
resistance to penetration for any load. This differs so greatly
from Brinell's suggestion that it brings up the question as to the
real utility of the Brinell number.

On reading Brinell's original paper [12] (German translation)
the author received the impression that he was attempting to de-

[11]Nature, 1928, Vol. III, p. 430.

[12]Baumaterialienkunde. 1900, Vol. 5, p 276, et seq.

velop a purely technological test, simple and accurate in the details of its manipulation, and which would give a single numerical expression for use as a "hardness number." That he was eminently successful is attested to by the widespread and continued use of his test for nearly a quarter of a century. Brinell appreciated that the load affected the hardness number and suggested testing at a constant impression diameter, but for practical purposes he preferred to use a constant load. He also tried measuring the depth of the impression but gave it up in preference to the diameter, as the latter is easier to measure. Furthermore, if the impression angle remains less than 90 degrees, the diameter varies more rapidly than the depth and so gives a more open scale. The load was selected to keep the impression angle below 90 degrees, e. g., 3000 kilograms for hard metals and 500 kilograms for soft metals.

The hardness number which he proposed, considering the use to which the test was to be put, was a matter of much less importance than the selection of the other features of the test. He could have used impression diameters, or 1000 times the reciprocals if he wished to get numbers which would increase with the hardness. The present paper is not intended in any way to discredit Brinell's test but rather to point out that if we are to analyze the test scientifically or to apply it to many special problems, the Meyer relationship and the mean pressure are to be preferred.

Several cases which are examples of this point may be of interest. A short time ago the author prepared a bar of annealed mild steel and a bar of cold rolled copper. The copper showed a higher Brinell number than the iron, but the iron would scratch the copper and in turn was not scratched by the copper. The question came up at once, "which was the harder metal?" Meyer's analysis gives us the very logical answer,—both. At low to medium loads, represented by the Brinell test, the copper actually resists penetration more than the iron does. This is reflected in the higher a value of the copper. At higher loads, represented by the scratching test, the iron is stronger. In other words, worked copper is harder than soft iron but worked iron is harder even than worked copper. The answer falls out very simply.

Let us suppose that a firm is stamping or pressing parts out

of mild steel and that they are controlling their steel purchases with the Brinell number. What might they do to insure getting uniformly hard sheets in the thinner sizes and which would run the same as their heavier sizes, assuming that they do not wish to stack the sheets for testing? First of all they could use smaller balls and pressures on the thin sheets and get comparable p values provided only that the $P:D^2$ relationship were observed. Secondly they could use the constants a and n as a control of quality and take advantage of the more open scale and greater accuracy which they provide. That is, they would specify certain a and n values for their material, rather than a certain Brinell number. Two hardness numbers may be very nearly equal and yet the two samples may be in quite different conditions of strain or one may be appreciably more ductile than the other. This illustrates the deficiency of our present methods of hardness testing. Interesting in this connection is the finding of Norbury[13] that a decreases and n increases for copper, as the annealing temperature is raised from 560 to 950 degrees Cent. This effect was scarcely perceptible with the scleroscope (magnifier hammer) or the Brinell test at 3000 kilograms.

In such a case the present hardness test may very easily give misleading information as to the hardness or ductility of the metal in question. A determination of a and n would show the metal in its true light. In this respect the author suggests to those working in this field, that they develop the possibilities put forth here.

For example, let us suppose that the metallurgical laboratory has made a study of the product and that they know the a and n values for their various materials in the annealed (i. e., most drastically annealed) condition and in various conditions of strain. Let us also suppose that they also know how to take into account the small variations in composition and purity of the products. Then it might be possible with one determination at say 500 kilograms to get both a and n. They will already know the two, log P : log d curves, for the conditions of low a and high n and of high a and low n, and therefore the point of intersection. Then by plotting the 500 kilogram point on the

[13]*Journal* Institute of Metals. No. 1, p. 407, 1923.

log-log paper, and drawing a line to the point of intersection, the whole line and therefore a and n could be determined.[14] Of

Table VI

Material	Comp.	a	n	p_m in kg/mm² for d=1 mm. and P=3000 Kg.		YP. TS. Kg/sq. mm.		EL. RA. in %	
Lead		20.3	1.91	25.8	...	...	...	...	..
Aluminum		28.5	2.07	36.3	42.4	...	...	...	..
Al. Alloy I	85 Al., 8 Cu., 5 Sn., 2 Ni	39.0	2.26	49.65	81.6	6.1	10.6	0.07	..
Al. Alloy II	80 Al., 7 Cu., 9 Sn., 4 Zn	41.0	2.26	52.25	85.6	7.1	14.0	1.25	..
Zn. Alloy	86 Zn., 0.4 Al. 5 Cu., 9 Sn	49.5	2.17	63.1	87.0	3.5	6.5	0.15	..
Rolled Cu. I		45.0	2.085	57.3	68.3	16.6	22.8	46	79
Rolled Cu. II		76.0	2.05	96.8	106	...	...	...	..
Brass		100.0	2.13	127	156	...	...	...	..
White Cast Iron		116.0	2.31	147	229	...	19.3	...	..
Gray Cast Iron I		81.0	2.38	103	181	...	13.4	...	..
Gray Cast Iron II		92.5	2.21	117	164	...	...	...	..
Mild Steel I		78.5	2.18	106	135	26.0	46.5	30	59
Mild Steel II		80.0	2.22	101	145	...	...	...	..
Mild Steel III		143.0	2.14	182	222	...	...	...	..
Mild Steel IV		73.5	2.22	93.7	135	...	...	...	..
Steel		174.0	2.20	221	283	...	...	...	..
Nickel Steel	0.04 Ni., 0.16 C.	67.3	2.22	85.4	124	14.2	36.6	18.7	31
Nickel Steel	3.01 Ni., 0.05 C.	76.0	2.22	96.8	144	29.2	40.8	29.9	71
Nickel Steel	2.96 Ni., 0.15 C.	84.8	2.28	108	166	31.8	47.9	25.7	59
Nickel Steel	3.10 Ni., 0.11 C.	86.5	2.20	110	152	23.4	42.6	25.7	42
Nickel Steel	3.15 Ni., 0.48 C.	174.0	2.22	221	294	...	49.5	0.3	0
Nickel Steel	3.13 Ni., 0.59 C.	167.0	2.32	213	316	52.5	97.5	13.0	39
Nickel Steel	0.08 Ni., 0.75 C.	95.0	2.35	121	203	20.8	59.4	13.8	26
Nickel Steel	0.14 Ni., 1.01 C.	170.0	2.29	216	310	48.9	100.3	8.9	13
Nickel Steel	3.20 Ni., 0.85 C.	186.0	2.30	236	338	58.6	108.9	11.1	22
Nickel Steel	16.3 Ni., 0 15 C.	230.0	2.32	293	420	...	117.0	9.2	56
Nickel Steel	11.90 Ni., 0.25 C.	258.0	2.32	329	664	...	165.9	8.9	46
Nickel Steel	16.26 Ni., 0.30 C.	270.0	2.26	344	452	...	140.2	10.8	51
Tin[1]		5.53	2.18	...	...	...	...	...	..
Zinc[1]		24	2.21	...	...	...	...	...	..
Cathode Cu.[2]	Fully annealed	16.7	2.45	...	...	...	...	...	..
Rolled Cu.[2]	Annealed	23.3	2.35	...	...	...	...	...	..

[1]O'Neill. [2]Norbury.

course, the 500 kilogram point would have to be accurately determined. One might also take advantage of the difference in the p_m values for the 500 and 3000 kilogram loads which is required for a given n and thus use it as a check on n but it is doubtful if the sensitivity of this method would be sufficient.

On leaving this subject, just one word of caution seems necessary. Thirty seconds are not long enough to insure getting

[14]This suggestion is based on the theory of the effect of plastic deformation (cold work) on a and n, which, as far as the author can now see, is sound. A few data which are available gave the following results: First, the author drew in the two lines mentioned and obtained their point of intersection. From this point, he drew a line through the 500 kilogram point on an intermediate line and noted that such a line checks with the 3000 kilogram points as found experimentally within 0.0 and 0.10 millimeter. This variation, in load, amounted to a maximum of 50 kilograms. In Brinell number, this variation would be around 2 points, from which one may get an idea of the accuracy of the method. The n's were 2.20 as found, and 2.16 as "calculated," and the a's, 41.6 and 43.3 respectively.

equilibrium between the load and the sample, and yet one must get equilibrium or these relationships are not obtained. The correct time interval which may be 10 to 20 minutes in some cases, must be ascertained and will be greater for the softer metals and higher loads. At one time the writer tested out this point with a Brinell machine, using a load of 3000 kilograms and 30 seconds and 10 minutes for the times. The two diameters were 6.63 and 6.73 millimeters, respectively. This affected the Brinell hardness by only three points but this error would be greater than is desirable for the determination of a and n. On the other hand, the procedure of plotting a number of points on log-log paper gives one a very good insight into the accuracy of his hardness determinations, for the points must fall on a straight line. An inaccurate determination stands out at once. We have no such check in our present method.

Table VI is included which gives a number of a and n values, which have been taken principally from the work of Meyer.

The Question Box
A Column Devoted to the Asking, Answering and Discussing of Practical Questions in Heat Treatment — Members Submitting Answers and Discussions Are Requested To Refer to Serial Numbers of Questions

NEW QUESTIONS

QUESTION NO. 135. From what material should the gears and pinions be made to be used in a galvanizing bath, that is, operated under molten zinc?

ANSWERS TO OLD QUESTIONS

QUESTION NO. 98. What heat treatment will give a pure martensite structure throughout the hardened area of a piece of steel 6 x 2 x 3½ inches?

———

QUESTION NO. 120. How does the carbon content affect the secondary hardness of high speed steels?

———

QUESTION NO. 129. Does full annealing chromium and tungsten magnet steel, before hardening, affect the magnetic properties? If so, what is the cause?

ANSWER. By D. K. Bullens, president, D. K. Bullens Co., Pottstown, Pa.

In answer to this question, the writer would state that from experience obtained in the manufacture of permanent magnets that annealing has a very decided affect upon the magnetic properties of magnet steels. This affect is especially noticeable in respect to coercivity. Repeated tests on tungsten magnet steel show the following coercivities in relation to the Brinell hardness numbers.

Brinell	Coercivity
350	56—63
300	48—52
200	30—35

QUESTION NO. 130. Is there any advantage in using notched-bar impact tests in the inspection of annealed tool steel bar stock? What does such a test show?

———

QUESTION NO. 131. Given an alloy of the brass or bronze type, in which there are no critical transformation points, suppose that through carelessness the metal has been overheated, producing an undesirably coarse crystalline structure, is it possible to refine the grain without remelting or mechanical work?

QUESTION NO. 132.   *Given an alloy of the following analysis as cast, would the addition of vanadium to the extent of 0.10 to 0.20 per cent decidedly improve the following physical qualities in either the "as cast" or heat treated alloy?   What heat treatment, if any, should be used to develop the following qualities?*

    1. Resistance to wear   2. Resistance to dynamic stresses

ANALYSIS

1.80 — 2.20 per cent carbon		.04	"	sulphur
.50 — .60 " manganese		.04	"	phosphorus
.30 — .40 " silicon		1.50 — 2.00	"	chromium

ANSWER.   By James Sorenson, metallurgical engineer, Four Wheel Drive Auto Co., Clintonville, Wis.

The effect of adding vanadium to a steel of the above mentioned chemical analysis would no doubt be noted in the improvement of the physical properties if heat treated.   This improvement is due chiefly to the action of the vanadium, which is an excellent scavenger and carries the point of deoxidization beyond any point obtainable by the use of silicon, manganese or aluminum, consequently, the steel treated with vanadium should be somewhat tougher and in a better condition to receive further treatment.

Again, upon breaking a piece of vanadium steel, a finer grain will be noted than with the ordinary carbon steel.   As to a suitable heat treatment for a steel of the above mentioned chemical analysis which will give good resistance to wear the following procedure should give good results:

Anneal at 1525 degrees Fahr.

Reheat to 1480 degrees Fahr. quench in oil.

Reheat to 550 degrees Fahr. cool slowly.

The following heat treatment should give good resistance to dynamic stresses:

Anneal at 1525 degrees Fahr.

Reheat to 1480 degrees Fahr. quench in oil.

Reheat to 1050 degrees Fahr. cool slowly.

Why not use a steel having a 0.50 per cent carbon, as this material could be heat treated so as to give excellent results, both in regard to resistance to wear and resistance to dynamic stresses.   It seems that in using an alloy steel with a carbon content as high as 1.8 to 2.20 per cent some trouble may be experienced due to brittleness.   Also if any machining is necessary, the 1.8 to 2.20 per cent carbon steel will naturally be more difficult to machine than a 0.50 per cent carbon.

QUESTION NO. 133.   *In annealing a carbon tool steel of 1.30 to 1.40 per cent carbon, are there any ill effects to the steel in allowing it to soak for an hour or more at 30 to 40 degrees Fahr. above the critical point?*

QUESTION NO. 134.   *What are the usual feeds and speeds used in machining both carbon and alloy automotive steels, when using high speed steel cutting tools?*

Reviews of Recent Patents
By
NELSON LITTELL, Patent Attorney
110 E. 42nd St., New York City
Member of A. S. S. T.

1,498,990, Robert Beyer, of Meran, Italy, Electric Furnace.

This patent relates to a furnace of a resistance type, adapted for quick heating to a high temperature and to maintaining a high temperature for a considerable length of time, in which the heating elements are mounted in
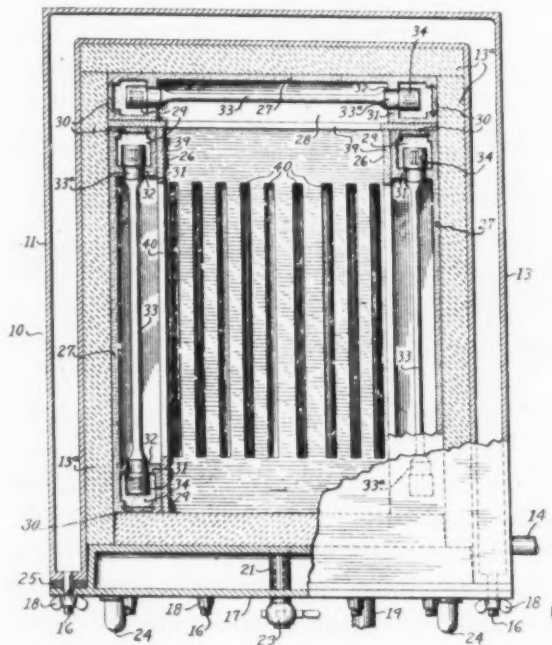
slab-like walls so as to conserve the heat and prevent injury to the heating elements from gases or acids produced during the operation of the furnace.

In the drawing, 11 indicates a double-walled outer casing which may be water cooled. Inside the casing 11 are refractory lining members 13 and inside these are slab-like heating walls 27, each of which is provided with rectangular pockets 29 at the ends thereof betweeen which the resistance elements 33 extend. Suitable cross bars or connectors are provided

1,499,068, Making Gray Iron, Augustus F. Meehan, of Chattanooga, Tennessee.

This patent relates to a method of producing gray iron of greater strength and uniformity than ordinary gray iron, but not too hard to be economically machined.

The process comprises melting an ordinary white iron mixture and

adding to the molten white iron calcium silicide or magnesium silicide which frees the bath of occluded gases and tends to throw out the carbon as graphite during cooling to produce gray iron from the white iron mixture.

1,499,801, Case-Hardening Process, Frank A. Bond, of Pittsburgh, Pennsylvania, assignor to United States Crain & Forging Co., a corporation of Delaware.

This patent describes a process of case hardening which comprises providing a fused bath of case hardening material preferably of a cyanide, preheating the articles to be treated to their upper point of decalesence and
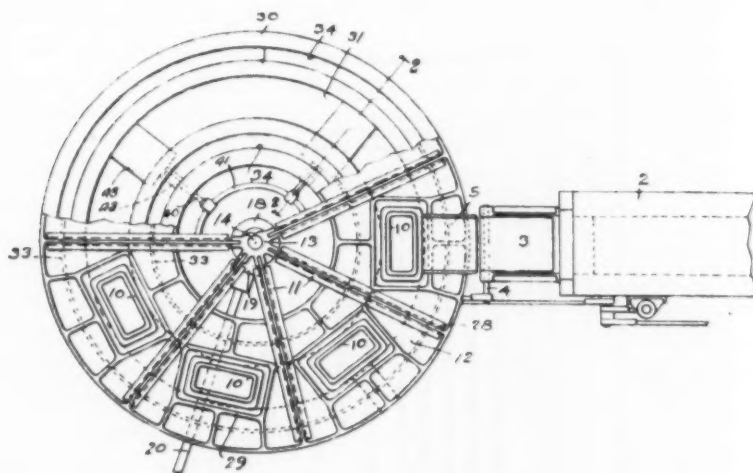
preferably to the temperature of the fused bath and then introducing the heated articles in the fused bath and keeping them there for a sufficient time to produce the depth of case required.

The inventor has stated that the idea of preheating the articles to the upper critical point and then inserting them into the fused bath is broadly new. In order to carry out the process in an efficient way, the patent provides a preheating chamber 2 through which the articles are continuously moved to preheat them to the proper temperature. A transferring device 3 on the end of the furnace is used to transfer the articles on to the apron 5 of the cyanide pots 10 from which they may be dropped into the pots. The cyanide pots 10 are mounted between the arms 11 of the turret 13 adapted to be rotated around the pivot 14 by any suitable driving mechanism. The bottoms of the pots 10 project into the annular furnace 31 and are heated therein. The rotation of the turret is timed so as to permit the articles in the pots 10 to remain in contact with the fused bath for the time necessary to impart the desired case.

Abstracts of Technical Articles

Brief Reviews of Publications of Interest
to Metallurgists and Steel Treaters

NON-RUSTING CHROMIUM-NICKEL STEELS. By B. Strauss, Fried. Krupp, A. G., Essen, Germany.

This paper was presented at the June meeting of the American Society for Testing Materials at Atlantic City. The author discusses the valuable properties of chromium as an alloy with iron and steel, and describes a number of experiments which have led to the development of two chromium-nickel steels. The applications of these steels are given.

CHARACTERISTICS OF SOME MATERIALS FOR BASE-METAL THERMOCOUPLES. By F. E. Bash, manager, technical department, Electrical Alloy Co., Morristown, N. J.

This paper was presented at the June meeting of the American Society for Testing Materials at Atlantic City, and discusses the important considerations in choosing the elements of thermocouples. Results of tests in which the thermo-electric properties of a number of alloys are determined against copper used as a standard material are given.

ACCELERATED FATIGUE TESTS AND NOTES ON THE ENDURANCE RANGE OF STEEL. By D. J. McAdam, Jr., metallurgist, U. S. Naval Engineering Experiment Station, Annapolis, Md.

This paper was presented at the June meeting of the American Society for Testing Materials at Atlantic City, and describes a method of investigating the endurance properties of metals by the "accelerated fatigue method."

ALUMINUM AND ITS IMPORTANCE IN THE ELECTRICAL INDUSTRY. By Mr. Wintermeyer in the *Journal* of the Institute of Metals, Vo. 29, page 753.

The author gives a general description of the preparation of pure aluminum as well as the physical and chemical properties of the metal. The modern applications of aluminum in electric machines are discussed.

FINDING ACTUAL COST OF CASTINGS. By George B. Cocker, state vice-president of the Southern Metal Trades association, in *Iron Trade Review*, August 14, 1924, page 421.

This article was taken from a paper presented at the Asheville, N. C., meeting of the Carolina members of the Southern Metal Trades association, July 9, 1924, and tells of a system for determining the selling price of castings, as devised by a Southern foundry. The author states that there are two factors used, namely, actual time required to produce castings and the amount of metal needed to pour them.

PRODUCTION AND USE OF REFINED SULPHUR. By Charles A. Newhall, consulting chemist and chemical engineer, Seattle, Wash., in *Chemical and Metallurgical Engineering*, July 28, 1924, page 144.

The above is a discussion of the technology of manufacturing refined sulphur and of the advantages and methods of commercial use.

TECHNOLOGY OF ZIRCONIUM AND ITS COMPOUNDS. By Frederick C. Nonamaker, chemical department, Welsbach Co., Gloucester, N. J., in *Chemical and Metallurgical Engineering*, July 28, 1924, page 151.

This article gives an intimate, authoritative view of the significant and unique development of the element zirconium, which exhibits properties of absorbing interest to many industries.

ELECTRICAL EQUIPMENT FOR MACHINE TOOLS. By John W. Harper, industrial engineering department, General Electric Co., in *American Machinist*, August 7, 1924, page 215.

In this article are given the general features of electrical equipment. The characteristics of the various types of motor controllers, and the duty each type is best fitted to perform, are covered.

NOTE DEFECTS IN CAST BRONZE. By R. L. Binney and N. I. Terbille, in *Foundry*, August 1, 1924, page 596.

The authors in this article, discuss the melting temperatures, mixtures, deoxidizers and their relative applications best suited to eliminate the defects which usually occur in producing cast brasses and bronzes.

STUDY STRUCTURE OF GRAY IRON. By J. W. Bolton, in *Foundry*, August 15, 1924, page 628.

In this article are discussed macroscopic and low-power magnification methods, which reveal the general structure of gray iron and semisteel. Microphotography is also considered.

THE MANUFACTURE OF COPPER WIRE. By W. M. Pettis, rolling mill expert, in *Metal Industry*, August 1924, page 309.

This article gives a description of the operations from wire bar to the finished wire.

MATERIALS FOR BASE-METAL THERMOCOUPLES. By F. E. Bash, manager, technical department, Electrical Alloy Co., Morristown, N. J., in *Forging-Stamping-Heat Treating*, August 1924, page 307.

In this article are discussed important considerations in choosing elements for thermocouples, and the thermo-electric properties of a number of alloys are determined against copper.

News of the Chapters

BOSTON CHAPTER

At a meeting of the Executive Committee of the Boston chapter of the American Society for Steel Treating, held on August 12th, the following committees were elected: Program Committee, S. W. Parker, chairman; L. D. Hawkridge, E. R. Fernald and H. B. Parker, members. Reception Committee: C. L. Stoot, chairman; W. J. Kunkel, C. Karle and Henry Foster, members. Membership Committee: L. E. Zurbach, chairman; E. R. S. Reeder, L. G. Bean, W. E. Adams, O. T. Smith and P. F. McDonald, members. Attendance Committee: R. A. Johnson, chairman; Ernest Carlson and R. A. Topham, members. Research Committee: H. E. Handy, chairman; Frank Kingdon, R. S. Williams and I. N. Zavarine, members. Finance Committee: F. H. Cole, chairman, and A. B. Day, member. Other business was also carried on at this meeting. It was decided that the Boston chapter should not join the Affiliated Society of Engineers of Boston. R. A. Johnson, chairman of the Attendance Committee, was appointed to prepare a year book to be known as the ''Who's Who of the Boston Chapter of the A. S. S. T.'' The Program Committee arranged for a meeting to be held the Friday night preceding the Convention, in order to arouse interest and to distribute badges to the Boston chapter membership.

GOLDEN GATE CHAPTER

The Golden Gate chapter of the American Society for Steel Treating held a meeting on July 23rd in the rooms of the Engineers' Club, 57 Post Street, San Francisco. The first speaker of the evening was H. S. Taylor, chief metallurgist of the Holt Manufacturing Company, Stockton, Calif., who gave a most interesting resume of recent articles published in Transactions, under the title, ''Can Grey Cast-Iron Be Carburized?'' The discussion that followed was generally shared in by all the members present and was very lively. E. H. Kottnauer of the Standard Oil Company at Richmond, Calif., gave a short talk concerning conditions as he found them in the East. S. R. Thurston, Bethlehem Shipbuilding Corporation, gave an interesting talk entitled, ''The Problems With Which the Steel Chemist Has to Deal.'' An interesting discussion followed this presentation.

The chapter held a very successful meeting on August 13th at the new Peerless Cafe in Oakland. E. H. Kottnauer spoke to the members, giving his experience in the field of heat treating. A very enthusiastic

discussion followed, which lasted for an hour. R. E. Surtees, who has spent a number of years in the heat treating plant of the Studebaker factory, also gave a short talk. This meeting was well attended.

LOS ANGELES CHAPTER

The Los Angeles chapter of the Society held a meeting on August 6th at the Los Angeles Creamery Dining Room. W. E. Nelson, Pacific coast representative for the Firth-Sterling Steel Company, was elected a delegate to represent the chapter at the Convention of the Society in Boston. One of the most interesting and beneficial illustrated talks which the chapter has had was given by Prof. W. H. Clapp of the California Institute of Technology of Pasadena, Calif. Prof. Clapp, throughout his talk on ''The Relation of Crystal Structure to Physical Properties of Steel,'' referred to mineral specimens, which have similar structures as iron and steel, followed by the display of the metal specimens. He showed physical property curves corresponding to the structures mentioned. Following the first part of his lecture, enthusiastic discussion ensued. The second part of his talk was arranged and illustrated with lantern slides, descriptive of microstructures, physical properties and chemical compositions. Equilibrium diagrams were also shown. It was truly a technical lecture for a layman's understanding, and as such the evening was considered very profitably spent. A very enjoyable dinner preceded the business and technical meeting.

PITTSBURGH CHAPTER

The Pittsburgh chapter of the American Society for Steel Treating at a recent meeting elected the following committees for the year. Meetings and Papers Committee: W. J. Merten, chairman; C. M. Johnson, A. S. Ogg, W. J. Priestley and W. I. McInerney, members. Membership Committee: N. B. Hoffman, chairman; W. H. Rieger, O. B. McMillen, J. N. Ludwig, Jr., and G. O. Loeffler, members. Publicity Committee: H. A. Neeb, chairman; E. C. Cook and D. L. Mathias, members. Reception Committee: G. L. Kronfeld, chairman; W. H. Phillips and DuRay Smith, members. Entertainment Committee: D. H. Horne, chairman; W. H. Phillips and DuRay Smith, members. Finance Committee: Prof. S. L. Goodale, chairman; T. D. Lynch and J. K. Miller, members.

The chapter held a meeting on September 2nd at 8:00 p. m., in the Blue Room of the William Penn Hotel. Dr. N. B. Hoffman of the Colonial Steel Company gave an interesting address entitled, ''Some Phases of the Metallurgy of Tool Steel.'' An interesting and instructive discussion followed this presentation. Dinner was served at 6:30 p. m. preceding the meeting.

EMPLOYMENT SERVICE BUREAU

The employment service bureau is for all members of the Society. If you wish a position, your want ad will be printed at a charge of 50c each insertion in two issues of the Transactions.

This service is also for employers, whether you are members of the Society or not. If you will notify this department of the position you have open, your ad will be published at 50c per insertion in two issues of the Transactions. Fee must accompany copy.

Important Notice

In addressing answers to advertisements on these pages, a stamped envelope containing your letter should be sent to AMERICAN SOCIETY FOR STEEL TREATING, 4600 Prospect Ave., Cleveland, O. It will be forwarded to the proper destination. It is necessary that letters should contain stamps for forwarding.

POSITIONS WANTED

MACHINIST with knowledge of metallography desires position. First class inspector with machine experience on machine tools and accurate automatic machine parts. Heat treatment inspection experience on tool steel and case carburized work. New England territory preferred. **Address 6-10.**

METALLURGIST or Assistant desires position in Philadelphia or New York district. At present employed. Four years shop experience in foundry and cupola control. Three years chemical analysis of ferrous and non-ferrous alloys. Supervision of heat treating, inspection and physical testing. One and one-half years as chemist and moulding foreman in steel foundry. Two years pyrometric and laboratory work on ball bearing steels. Technical graduate. Age 28. Single. **Address 6-15.**

FOREMAN HEAT TREATING PLANT. Graduate in metallography and industrial management desires position in charge of heat treating plant. 12 years' practical experience as hardener on tools, carburizing, heat treating and brazing. 10 years' experience in supervising the erection and demonstration of furnaces for various metallurgical purposes. **Address 8-5.**

METALLOGRAPHIST-METALLURGIST wants employment when he returns from Europe on September 15th. Graduated from Ohio State University and took advanced work at Columbia University in metallurgy. Formerly in charge of small heat-treating department. 5 years' experience covers routine analysis, metallography, heat-treating, hardening of tool and high speed steel. Knowledge of non-ferrous metallography and physical testing. Inclined to research work. Can furnish reference. **Address 9-20.**

TOOL HARDENER desires position. Familiar with drop forge dies, shear knives and all tool steels. 12 years' experience. Can give first class references. Capable of taking charge of hardening room. Location in Los Angeles or vicinity preferred. **Address 9-1.**

CHEMIST AND METALLURGIST desires position. Capable of handling or developing chemical and metallurgical laboratory. Experienced in microscopic examination of steel for controlling heat treating in industrial plant. Familiar with latest forging, annealing and hardening practices and equipment with pyrometric control. Capable of carrying out experimental work to improve product. Prefer Chicago location. Married. **Address 7-15.**

POSITIONS WANTED

HEAT TREATER desires position. Can give references. Location preferred—Cleveland, Toledo or Detroit. **Address 7-5.**

POSITIONS OPEN

METALLOGRAPHIST wanted for research department of large manufacturing concern. Extensive experience is not required, but good training is essential. State age, nationality, training and salary required. **Address 9-10.**

METALLURGIST skilled in the theory and practice of physical metallurgy. Applicant must have a university training with from three to five years' practical experience in heat treatment and factory control. State age, experience and practical experience. **Address 8-15.**

WANTED RECENT TECHNICAL GRADUATE for metallurgical research on non-ferrous alloys. Good fundamental training in the principles of metallography required. In replying give education and training, industrial experience, age, religion and nationality, whether married or single, and references. **Address 7-10.**

WANTED—Tool steel salesman by high grade tool steel mill for work in Chicago and adjacent territory. Salary and commission arrangement. Very fine proposition for high grade man. One who has travelled. Chicago territory preferred. State full experience. **Address 8-10.**

WANTED

WANTED—Stanton Repeated Impact Testing Machine. Second hand. Advise condition and price. **Address 7-20.**

WANTED—Used scleroscope. Must be in very good condition. **Address 9-15.**

WANTED—Used metallurgical microscope with camera, objectives and polishing equipment. State condition and price. **Address 9-5.**

Items of Interest

WILLIAM P. HAMMOND and Nelson Littell announce the forming of a partnership for the practice of Patent and Trade Mark Law under the firm name of Hammond & Littell, with offices at 110 East 42nd Street, New York, N. Y. William P. Hammond has been engaged in the practice of Patent Law in New York for over fifteen years and has been especially prominent for his personal inventions and promotion work in the automotive field. Nelson Littell was for several years an examiner in the Metallurgical Division of the Patent Office and is known to the readers of the Transactions through the "Reviews of Recent Patents."

James H. Knapp, Los Angeles, industrial furnace engineer, and Pacific coast representative for Tate-Jones & Co., Inc., Leeds & Northrup Co., Eclipse Fuel Engineering Co., Seaboard Refractories Co. and E. J. Cood Co., is moving his offices from 769 South Central avenue to 731 Merchants National Bank building and his warehouse to the Central Mfg. district at Fiftieth and Loma streets.

Harry S. Smith, for the last 18 months identified with the Poldi Steel Corporation of America as its Chicago district sales agent, has resigned and will be succeeded by C. O. Sternagle, for a number of years in charge of the Chicago branch of the Colonial Steel Co.

K. G. Jansson, assistant works manager of the Springfield, Ohio, plant of the Ohio Steel Foundry Co., has resigned to accept a position with the Lima Metals Foundry, in which he has purchased an interest. Recently there were several changes at the Springfield works, T. H. Harvey, works manager, having been promoted to vice-president in charge of sales. C. J. Gilmore of Lima has been made production manager of the Lima and Springfield works.

Dr. Ancel St. John has resigned from the staff of the Union Carbide & Carbon Research Laboratories, Inc., Long Island City, N. Y., and will open offices as a consulting and research physicist, specializing in the industrial application of X-rays. Dr. St. John has been associated as research physicist with the Long Island City laboratories since their opening, and previously was connected with a predecessor group, the Research Laboratories of the National Carbon Co., Inc., Cleveland. During this period he has devoted himself almost exclusively to the application of X-rays in the carbon and metallurgical industries, through crystal analysis of carbon and alloy materials and through radiographic and fluoroscopic inspection of metal objects for hidden defects. When Dr. St. John began this work at Cleveland six years ago he was the first investigator spending his entire time in evaluating the possibilities of X-rays as an aid to industry, and the Union Carbide & Carbon Corporation was probably

the first industrial organization to make X-ray research a major department in the laboratory. Recently Dr. St. John has been endeavoring through publications and lectures to give the steel industry an inkling of what X-rays have done and can do toward improving methods and products, and he believes that the time is opportune for making his training and experience more generally available, not only to the steel trade, but also to chemical and metallurgical industries. For the present Dr. St. John's mail address is Room 404, 505 Fifth Avenue, New York.

Sam Tour, metallurgist with the Doehler Die-Casting Company, announces the removal of his headquarters from the Brooklyn to the Batavia plant, effective August first, 1924. There will be no discontinuance of the work Mr. Tour has been doing, but it will be carried on at, and directed from the new headquarters.

P. S. Williams has resigned as chemical engineer with the Standard Oil Company and is now manager of the Soda Lake Plant of the Pacific Distributing Corporation at McKittrick, Calif.

Carrick Engineering Company, Chicago, have recently published their catalogue No. 99, entitled, "The Automatic Control of Combustion," which is a very thorough discussion of automatic control methods and systems. It points out the limitations of the various systems and why they fail. It analyzes the conditions to be met in co-ordinating supply of steam with the demand and gives some very interesting charts of steam pressure. Copies of this 32-page treatise may be obtained upon request.

A 16-page bulletin entitled "Systems for the Automatic Control of Combustion" has also been published recently by the Carrick Engineering Company of Chicago. This gives complete specifications together with diagrams and list of equipment required for thirty-three distinct methods of automatically controlling boiler-room equipment. This bulletin has been prepared especially for consulting and designing engineers seeking accurate. authoritative and complete information in an accessible form. Thirteen methods of controlling powdered coal are included. Each method is illustrated and described and the necessary apparatus given. Copies of this may be obtained upon request.

The United States Civil Service Commission announces the following open competitive examination: for the positions of Metallurgist, $3,800 a year. Associate Metallurgist, $3,000 a year. Assistant Metallurgist, $2,400 a year.

Receipt of applications will close September 30. The examinations are to fill vacancies under the Bureau of Mines, Department of the Interior, at the entrance salaries stated above. Advancement in pay may be made without change in assignment up to $5,000 for metallurgist, $3,600 for associate metallurgist, and $3,000 for assistant metallurgist.

Applicants for any of these positions must have been graduated with a bachelor's degree from an institution of recognized standing, with major work in chemistry, physics, or metallurgy, and in addition, have had certain other specified training and experience.

Applicants must qualify in at least one of the following optional sub-

jects: Physical metallurgy, electrometallurgy, hydrometallurgy, lead and zinc metallurgy, iron and steel metallurgy, copper metallurgy, or some specialized line of metallurgy not included in any of the above.

Competitors will not be required to report for examination at any place, but will be rated on their education, training, experience, fitness, and publications, reports or thesis to be filed with the application.

Full information and application blanks may be obtained from the United States Civil Service Commission, Washington, D. C., or the secretary of the board of U. S. civil-service examiners at the post office or customhouse in any city.

Columbia Tool Steel Company, Chicago Heights, Illinois, have recently published "Columbia Tool Steel Handbook," which is a complete treatise on the use and handling of Columbia Tool Steels, together with new data and information.

H. M. German, formerly with the Ohen-Bishop, Columbus, Ohio, has accepted a position as metallurgist with the Universal Steel Company, Bridgeville, Pa.

The W. A. Jones Foundry and Machine Company, Chicago, have just placed the "Jones Double Thrust Worm Box" on the market. It provides an accurate and rigid support for the worm shaft and holds a liberal supply of oil, in which the worm operates. There is also provided finished thrust washers at both ends of the worm, consisting of two steel and the center one of hard fibre. The bearings are babbitted and bored; also faced on ends. These boxes are now made in standard sizes to suit standard cut steel worms as made by this company, and both the boxes and gears are covered by their new catalog No. 29, entitled, "Jones' Gears," which is just off the press. These boxes are recommended to be used with open Worm Gear Drives when something less expensive than a completely enclosed unit must be used.

Catalog No. 29, mentioned above, contains 224 pages of specific detailed information with reference to the Jones Worm Box, and will be sent upon request.

"Crystal Structure and Its Applications" was the subject of 12 lectures given early in July before the graduate students of Pennsylvania State college, State College, Pa., by Dr. Wheeler P. Davey of the research laboratory of the General Electric Co., Schenectady, N. Y. Both the theory and application of X-ray analysis methods to chemistry and metallurgy were considered in the lectures, which were attended by the students and faculty in the physics, chemistry and metallurgy courses. Dr. Davey has been prominent in the development of X-ray crystal analysis apparatus and is the author of numerous papers on the subject. Apparatus designed by the General Electric Co. has been installed by the college for research on the structure of matter.